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of
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NO. 206

ALLENTOWN QUADRANGLE

MINERAL RESOURCES

By

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Published in cooperation with the United States Geological Survey

Department of Forests and Waters
R. Y. Stuart, Secretary

Topographic and Geologic Survey
G. H. Ashley, State Geologist

LETTER OF TRANSMITTAL.

R. Y. Stuart, Secretary.

Department of Forests and Waters.

Sir:

I have the honor to transmit herewith for printing, a report on the Mineral Resources of the Allentown Quadrangle by Professor B. L. Miller, Head of the Department of Geology of Lehigh University and cooperating geologist of this Survey. This is one of a number of detailed reports to be submitted, all of which will together constitute the Topographic and Geologic Atlas of Pennsylvania. The report covers the area of a quadrangle, lying between 15′ lines of latitude and longitude. In form and character it follows the many "folios" and "economic bulletins" previously published by the State and Federal governments on the geology of Pennsylvania.

The mineral resources of the region are of much financial interest. They include the heart of the Lehigh cement district, containing the largest cement mill in the world; the most important zinc deposits known in the State; also iron, slate, ochre and other deposits of value.

The expenses of the survey and the preparation of the report had been borne entirely by the U. S. Geological Survey. I asked permission to publish it, first, because of the many requests for information on the region covered; and second, because its publication by the Federal Survey seemed likely to be greatly delayed, by the inadequate printing appropriation of that Survey.

Respectfully submitted,

Geo. H. Ashley

State Geologist.

May, 1924.

PREFACE.

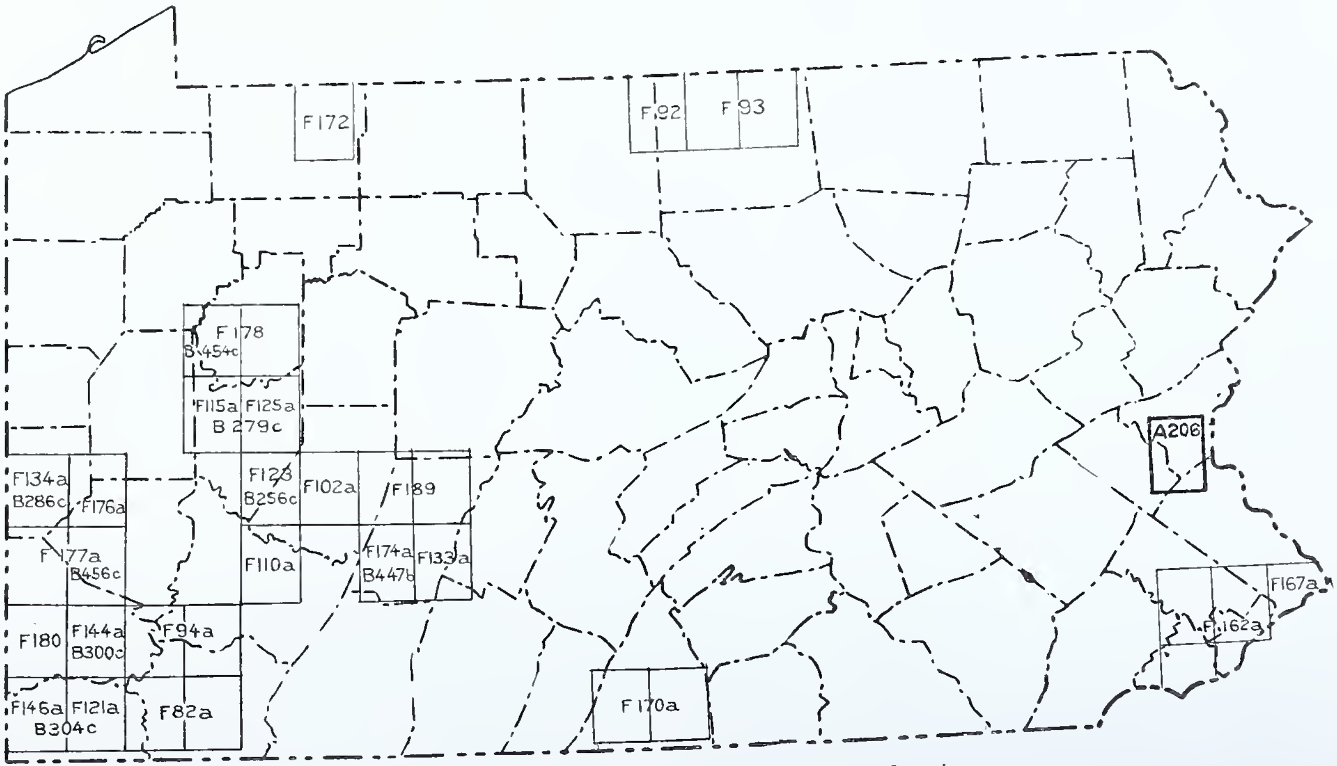
The Topographic and Geologic Atlas of Pennsylvania presents the results of the Survey's "thorough and extended survey of the State for the purpose of elucidating the geology and topography of the State." (Act of June 7, 1919, establishing Survey.)

The Act further provides: "The Survey shall disclose such chemical analysis and location of ores, coals, oils, clays, soils, fertilizing and other useful minerals, and of waters, as shall be necessary to afford the agricultural, mining, metallurgical, and other interests of the State, a clear insight into the character of its resources. The Survey shall also disclose the location and character of such rock formation as may be useful in the construction of highways or for any other purpose".

The results of the surveys may, in accordance with the provisions of the Act, be presented in the form of several series of publications as follows:

1. Topographic Atlas Sheets 16 x 20 inches: The surveys for these sheets are made by the State in cooperation with the U. S. Geological Survey, each paying half the costs. The engraving, printing and distribution of these sheets is done by the U. S. Geological Survey at Washington, D. C.

2. The Topographic and Geologic Atlas: Maps and texts showing and describing the topography, geology and mineral resources of the State by quadrangles. This series continues and supplements all "folios" and "economic bulletins" of Pennsylvania already published by the U. S. Geological Survey in cooperation with the State. Each quadrangle is an area about 17½ miles long from north to south and about 13½ miles wide from east to west and is represented by a single map or sheet. The quadrangles are numbered from west to east and from north to south. Sheet No. 206 is in the twenty-first row from the western edge, and the sixth sheet from the northern boundary of the State. The reports constituting the atlas will bear the same numbers. The following figure shows the sheets already issued, and the distribution status of each. (The numbers on folios and bulletins of the U. S. Geological Survey do not follow this system.)



Key map of folios and bulletins in Pennsylvania.

a. Out of print. Consult in libraries.
b. Obtain from The Director, U. S. Geological Survey at Washington. D. C.
c. Obtain from the Superintendent of Documents, Washington, D. C.
The numbers designate the publications.

3. County Reports: As the Atlas Sheets and Reports are highly detailed and somewhat technical, a series of County Reports will present the general facts in more popular language, and on maps without topography. These reports will also review the broader aspects of the subject, and in particular will present the detailed Soil Maps and Soil Reports.

4. Mineral Resources: These reports are confined to describing and showing the location of a single mineral resource over the State, with studies of the technology, including the mining, preparation and marketing of the minerals.

5. Underground Water Resources: In general, water resources will be discussed in the County Reports or in the Topographic and Geologic Atlas, but general studies on underground water supplies will follow in a fifth series of reports.

6. Soil Reports: In general, Soil Maps and Reports will accompany the County Reports, but general maps or discussions on soil conditions will fall in this series.

This report, having been prepared before the present State Survey was established, does not follow the stratigraphic nomenclature to be adopted for all new reports.

However, as the stratigraphy plays a very small part in this report, it does not seem necessary to recast that portion of the report. This report has had the advantage of a revision by Professor Miller, immediately preceding its offer for publication.

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ILLUSTRATIONS

Mineral Resources of the Allentown Quadrangle, Pennsylvania

By Benjamin LeRoy Miller.

INTRODUCTION.

GENERAL RELATIONS.

The Allentown quadrangle covers an area of 226.73 square miles in eastern Pennsylvania, lying between parallels 40° 30′ and 40° 45′ and meridians 75° 15′ and 75° 30′. It includes parts of Lehigh, Northampton, and Bucks counties. The quadrangle is named from the principal city within it. See Plate I in pocket.

Figure 1. Index map showing location of Allentown quadrangle.

CLIMATE AND VEGETATION.

The mean annual temperature of the region is about 51°. In the more elevated areas the summer is not marked by so great extremes of heat as those that prevail in the valleys, the night temperatures in particular being notably lower. Frosts come later in the autumn on the hills and on the ridges of the mountains than in the adjoining valleys. In most years there are no frosts that injure vegetation long before October, and in some there are no severe frosts before November.

The prevailing winds are from the west; in the summer they are from the southwest or south of west, and in the winter from north of west and northwest.

The average annual rainfall in the region is about 45 inches. In ordinary dry years it falls as low as 35 inches and in wet years it reaches 55 inches or more. The rainfall is almost equally distributed between the seasons, though there is a slight excess in the summer—28 per cent as against 24 per cent for each of the other seasons. The heaviest average rainfall is in June, July, and August—over 4 inches in each month—owing to the prevalence of summer thunderstorms. February is the driest month, the average precipitation for that month being about 3.20 inches.

The Great Valley, the Valley of Saucon Creek, and the Triassic lowland have been largely deforested, and the remaining timber is chiefly in scattered woodlots. The mountains are well wooded, and over 50 per cent of the area is still in timber, all second growth. The ridges that rise above the lowland are mostly forested.

The forests of eastern Pennsylvania and northern New Jersey are of the mixed hardwood type, the chief components being rock oak, white oak, red oak, hickory, maple, elm, and beech. Within the last few years the chestnut trees have been killed by the chestnut blight. Conifers are represented by pitch pine and white pine, which occupy the thinnest soils on the ridges; by red cedar in old fields or openings, and by hemlock and black spruce in moist ground. By repeated unregulated cutting and to some extent by fires the productive value of the forest has become low, but it is being restored by degrees through the growing disposition of the owners to practice forestry, and a better forest is in prospect.

CULTURE.

All parts of the quadrangle are rather thickly populated except the steeper slopes of the several mountainous areas, yet even the highest and most rugged mountains and hills afford sites for numerous houses, especially where the tops are moderately level, and many

farmhouses are built on steep slopes. Probably few places within the quadrangle are more than half a mile distant from the nearest residence. Except a few summer homes that stand on the tops of the mountains all the houses have been built for permanent use. The limestone belts, particularly the Great Valley, are most thickly inhabited, containing practically all the cities and towns, and the farming districts within the limestone regions are likewise more densely settled than those in the areas of gneiss and shale.

The principal cities and towns of the Allentown quadrangle are Allentown, Bethlehem, Catasauqua, Nazareth, Bath, Northampton, Siegfried, Coplay, Hokendauqua, Fullerton, Emaus, Hellertown, Freemansburg, Springtown, Spring Valley, Center Valley, Coopersburg, and Limeport. There are, besides the above, about 25 smaller villages that range from 50 to 500 in population. With the exception of Coopersburg all the towns named are underlain entirely or in part by limestone. Nearly all are in the Great Valley or in offshoots of it.

The quadrangle is covered with a network of highways that renders nearly all parts of it readily accessible. In the Great Valley the roads run in all directions, with little regard to the drainage lines. In other parts of the quadrangle, where the differences in elevation between the stream divides and the stream channels are greater, the roads follow either the divides or the valleys. In the belt of Martinsburg shale in the northwestern portion of the quadrangle and in the regions underlain by Triassic shale in the southern portion of the quadrangle the greater number of main roads follow the divides, but in the areas of gneiss, where the crests of the stream divides are more irregular and the tops of the mountains less well adapted for cultivation, most of the roads follow the valleys. Most of the roads in the valleys and the main roads across the mountains are good, a number of them having been rebuilt in recent years according to modern principles of road engineering. On the other hand, a few mountain roads have steep grades and rough surfaces and are impassable for any but the lightest vehicles.

Several main lines of railroad cross the quadrangle and branch lines reach nearly all parts of it. The Lehigh Valley Railroad and the Central Railroad of New Jersey traverse the entire width of the quadrangle, following the banks of Lehigh River from the northwestern portion of the quadrangle to Easton and thence continuing eastward to New York. The Lehigh Valley Railroad also operates a branch line that follows Bushkill Creek from Easton to Stockertown. The Philadelphia & Reading Railway operates three branch lines within the Allentown quadrangle—one traversing the Saucon Valley between Bethlehem and Philadelphia, one extending from Allentown to Reading, and the other from Allentown southward through the Perkiomen Valley. The Delaware, Lackawanna & Western Railroad has a branch

line that traverses the cement region of the northern portion of the quadrangle. The Lehigh & New England Railroad has a line that follows Monocacy Creek north from Bethlehem and another that extends from Allentown northeastward through the cement belt. A short line of railroad not now in use extends from Riegelsville across the southeast corner of the Allentown quadrangle to Quakertown, passing near Springtown and Pleasant Valley.

Besides the steam lines there are numerous trolley lines that connect nearly all the towns of the quadrangle with towns and cities outside the quadrangle, such as Philadelphia, Reading, Slatington, Bangor, and Delaware Water Gap. The following cities and towns are connected by trolleys: Allentown, Fullerton, Catasauqua, Northampton, Siegfried, Emaus, Mountainville, Center Valley, Coopersburg, Seidersville, Colesville, Friedensville, Aineyville, Rittersville, Bethlehem, Hellertown, Freemansburg, Butztown, Farmersville, Brodhead, Newburg, Nazareth, Bath, and Tatamy. Some of these places are connected by two lines. Two lines extend from Allentown to Easton, one passing through Bethlehem and Farmersville, and the other on the south side of Lehigh River through Bethlehem and Shimersville to Freemansburg.

A canal owned and operated by the Lehigh Coal and Navigation Co. follows Lehigh River across the Allentown quadrangle to Easton and thence down the Delaware. It was built in 1824 and is still operated for the transportation of anthracite from the coal regions to the manufacturing towns along Lehigh and Delaware rivers. Several dams have been built in Lehigh River to divert water into the canal; the main ones within the quadrangle are at Allentown and Island Park. In some places the canal boats use the river for short distances.

Agriculture is the chief occupation of the rural part of the population, and practically every part of the quadrangle is under cultivation with the exception of the rugged gneiss hills. The principal crops are wheat, corn, hay, oats, barley, and potatoes.

In some places there is considerable dairying. In the limestone valleys farm land ranges from $75 to $150 an acre, but elsewhere the value is considerably less.

The steep gneiss hills are covered with timber which has been cut over several times but annually produces considerable lumber.

The urban population is primarily engaged in the manufacturing industries. The manufacture of cement, which is the chief industry of the quadrangle, exclusive of farming, is centered in a belt that extends from Nazareth to Coplay. Limestone and other quarries are also extensively operated, and formerly the slate quarries and the iron and zinc mines made a large production. Blast furnaces and steel plants in several towns date from the period when iron was extensively mined in the region. The manufacture of textile products is

an important industry, and silk and knitting mills are located in almost every town and city. Numerous other manufacturing establishments make a wide range of products—machinery, wire, nails, coke, clothing, flour, cigars, and other articles. With the exception of the cement and other industries that depend upon quarry products, no relation exists between the manufacturing industries and the geology of the region except as the geologic conditions determine easy routes for transportation. The proximity to the coal regions and to the great centers of population and industry have been the chief factors in the industrial development of the region.

TOPOGRAPHY.

The Allentown quadrangle includes parts of the three divisions of the Appalachian province. The northern portion lies within the Kittatinny or Great Valley; the central and south-central portions constitute part of the Appalachian Mountains or Highlands; and the southeastern portion lies within the Piedmont Plateau.

All the larger topographic features of the quadrangle are the result of long-continued erosion, which acted on rocks of different structure and texture and of different degrees of resistance, in several geologic periods, during which the land stood at different altitudes above sea level.

RELIEF.

Kittatinny or Great Valley.

The Kittatinny or Great Valley, which includes more than half of the Allentown quadrangle, is occupied by belts of limestone and shale that in general trend northeastward. With few exceptions the limestones, owing to their less resistant character, occupy the greater depression. This arrangement is so uniform that a fairly accurate geologic map could be prepared on the basis of the topography alone, as is well shown by the rocks at Bath, which is located at the contact of the limestone and the shale and slate of the Martinsburg formation, the hills being formed of the shale and slate, whereas the broad lower-lying plain to the south is underlain by the limestone.

The general surface of the belt of shale which occupies the northwest portion of the Allentown quadrangle is a rolling plateau that is trenched by streams and everywhere so much eroded that its plateau character is obscured and in some places obliterated, though it is evident in the vicinity of Seemsville and in the flat-topped hills north and northwest of Bath. These comparatively level areas, which have an altitude of 600 to 760 feet above sea level, are the remnants of an old peneplain that was formed during the Tertiary period and that has been named the Harrisburg peneplain from its typical develop-

ment in the Susquehanna valley near Harrisburg. The region underlain by the shale has been greatly dissected by streams that have cut narrow, steep-sided valleys to depths of 200 to 300 feet below the former level. In the development of streams there seems to have been little regularity, and the hills are of various sizes and shapes. They present the greatest similarity in the steep slopes and the smooth and flowing outlines that are characteristic of shale belts.

The surface of the hills formed by the belt of shale ranges from 560 to 840 feet above sea level. The greatest elevation is near Dannersville, and from that point there is a general slope to the south. The old plateau surface was far from level, but it was much less hilly than the present surface, and its average altitude was about 200 feet below that of the bordering uplands.

The limestone belts are marked by irregular hills and ridges, similar in general features to those of the shale belts but less pronounced. The hilltops are remnants of a former plain that stood 200 to 350 feet below that marked by the tops of the hills formed by the shale. The rock terraces bordering the meandering Hokendauqua Creek in the northwestern part of the quadrangle, within the shale belt, may be correlated with this surface, but in general it has not been recognized in the Great Valley except in the limestone areas.

The average altitude of the limestone hills is about 400 feet above sea level. The tops of these hills are fairly level, and they form the remnants of a late Tertiary peneplain which has long been called the Somerville peneplain, from Somerville, N. J., but as this name has been used for several different peneplains it is proposed to substitute the term "Swarthmore" for the peneplain so well represented in the limestone areas of this quadrangle.

In detail the relief of the limestone belts presents strong contrasts to that of the shale belts. The surface is rolling, and few steep slopes occur except along some of the streams, where jagged outcrops of limestone form nearly vertical cliffs of moderate height. Streams are less numerous, and the entire region is much less dissected.

In a few places steep hills of small size rise abruptly above the surrounding country, such as the 440-foot hill 1 mile northwest of Shoenersville, but these are exceptional. The limestone belts are also characterized by sinks or depressions. These sinks differ greatly in size and shape; some of them are 20 to 50 feet deep, nearly circular, and steep sided, but others are mere shallow saucer-shaped depressions. Small streams flow into a few of these depressions and disappear underground; others are occupied by swamps or small ponds, but most of these ponds are small and contain water only for a few hours after rains.

Within the limestone belt there are two small hills—Quaker Hill and Pine Top, about 2½ miles north of Bethlehem—that belong geo-

logically to the Appalachian Mountains. They owe their present elevation to a pronounced fault that bounds the hills on the north.

The Appalachian Mountains.

The Appalachian Mountains, known as the Highlands in New Jersey and as South Mountain, Durham Hills, or Reading Hills in Pennsylvania, form a belt of rugged hills that extends diagonally across the Allentown quadrangle. Lehigh River, which flows along the north flank of these hills between Allentown and Easton, sharply divides them from the limestone belt of the Great Valley. Some small areas of limestone occur on the south side of the river, but they do not materially alter the topographic characteristics. The district is in general a plateau of erosion which is formed by resistant rocks and which has a fairly uniform altitude, ranging from 1,000 feet above sea level in the northeastern to about 800 feet in the southwestern part of the quadrangle. The plateau, however, is so intersected by valleys that in many places it loses its plateau character and is made up of flat-topped, steep-sided ridges that trend northeastward and are separated by valleys from 1 to 3 miles wide. So completely are the hills interrupted by these valleys and so widely are the parts separated that the divisions have received distinct names, such as South Mountain and Hexenkopf Hill.

The flat-topped mountains of the Appalachians represent the remnants of the Schooley peneplain. Probably the tops of some of the mountains have been lowered very little below the level of the old peneplain, as they conform very closely to the elevations where large portions of the old peneplain still remain, as in New Jersey.

The northeastward-trending intermountain valleys which break the Appalachians into separate mountain masses range in width from half a mile to 6 miles. The extreme width is attained only through the merging of several of these valleys which in their upper courses are separated by mountain ridges. The valley drained by Saucon Creek and known as Saucon Valley is the best example of such valleys in the Allentown quadrangle.

The bottoms of these valleys are by no means level, yet when compared with the slopes and heights of the bordering uplands, they can be properly termed flat-bottomed.

Piedmont Plateau.

The southeastern portion of the Allentown quadrangle includes portions of the Piedmont Plateau. The surface as a whole is considerably lower than that of the Appalachian Mountains, but the two districts are not everywhere sharply separated. With the exception of a few hills of pre-Cambrian and Cambrian rocks, such as those south and southeast of Springtown, the Piedmont Plateau of this quadrangle is composed of rocks of Triassic age.

The surface has a general southeastward slope but shows considerable diversity in altitude, ranging from 400 to 600 feet above sea level.

The uplands present a gently rolling surface which has few angular prominences. Although somewhat lower than the remnants of the Harrisburg peneplain in the northwestern portion of the Allentown quadrangle they are referred to the same period of peneplanation. The two areas, although not related geologically, are strikingly similar in their lithologic and topographic characteristics.

Within the Piedmont Plateau area are two hills whose crests stand at altitudes closely concordant with that of the southeastern margin of the dissected plateau of the Appalachians, to which they belong physiographically, though geographically and geologically they are a part of the Piedmont area. These hills are the flint hill south of Leithsville and the diabase hill 1 mile southwest of Fairmount. They owe their greater altitude to the more resistant rocks that compose them, in comparison with the shales and shaly sandstones that constitute the greater portion of the rocks of the Piedmont Plateau of this region.

DRAINAGE.

With the exception of small areas in the northeast and southeast corners the Allentown quadrangle is drained by Lehigh River and its tributaries. Bushkill Creek, a tributary of Delaware River, drains a small region in the northeastern portion, and the headwaters of Durham Creek, also a tributary of the Delaware, drain the region around Springtown.

Lehigh River enters the Allentown quadrangle a mile above Coplay and flows southeastward to Allentown, thence east-northeastward across the quadrangle, uniting with Delaware River at Easton, Pa., approximately 23 miles below Coplay. It receives the drainage of about seven-eighths of Allentown quadrangle. The Lehigh rises in Wayne County and has a drainage area of approximately 1,375 square miles. Where it enters the quadrangle it has an elevation of 280 feet above sea level and where it empties into the Delaware an elevation slightly less than 180 feet. The average fall in this reach is therefore somewhat less than 4½ feet to the mile. Low dams have been built in the river at Allentown and Island Park for the purpose of diverting water into the canal of the Lehigh Coal & Navigation Co. As small barriers have been built across the river at several other places, there are few natural rapids.

Although Lehigh River within the quadrangle is confined entirely to the limestones of the Great Valley it is bordered by bluffs throughout much of its course. Few of these exceed 100 feet in height,

although in a few places where the river strikes the gneiss hills the south side of the valley rises rather precipitously to a height of more than 400 feet above the river. Vertical cliffs of limestone alternate with grass-covered slopes or narrow alluvial plains and apparently have little relation to the bends in the river. Steep bluffs may occur on both the inner and the outer curves of the river bends and also where the river flows in a nearly straight course, and the same principle applies to the gentle slopes and to a somewhat less degree to the bordering flood plains.

The flood plains that border Lehigh River are discontinuous and narrow and in few places rise as much as 20 feet above the river. The most prominent exception is the flood plain on the south side of the river about 1½ miles west of Bethlehem, portions of which rise approximately 30 feet above the river. The topographic map shows ten islands in the Lehigh within the confines of the quadrangle, but one of these, Calypso Island, at Bethlehem, has been joined by artificial excavation and filling to the south bank. The islands are low and are composed entirely of river alluvium. They are rather heavily wooded and afford pleasant picnic grounds; Smith Island, known as Island Park, is the site of a summer resort.

The chief tributaries of Lehigh River within the quadrangle in order downstream are Hokendauqua, Coplay, Catasauqua, Jordan, Monocacy, and Saucon creeks. All these streams flow through limestone areas and have a low gradient. A few small unnamed streams that enter the river from the gneiss areas below Freemansburg have much greater fall and are characterized by small cascades.

Hokendauqua Creek, in the northwest corner of the quadrangle, is confined almost entirely to the belt of Ordovician shales and slates, and it exhibits the characteristics of the larger creeks that drain this region. It is a meandering stream that has well-developed flood plains about 200 feet below the level of the uplands. The valley slopes are steep yet smooth and rounded, with few outcrops of rock. The lower 2½ miles of its course is through argillaceous limestone. The stream becomes less winding, the steep rounded slopes of the valley change to gentle grass-covered surfaces on the inner curves of the stream bends, and nearly vertical cliffs of jagged limestone border the creek on the outer sides of the bends.

Catasauqua and Monocacy creeks, the upper courses of which are confined to the slate belt whereas their major portions are included in the limestones of the Great Valley, present characteristics similar to those of Hokendauqua Creek, though both streams, especially the Monocacy, show striking dissimilarities in the number and character of their tributaries in the slate and limestone belts. The tributaries in the slate belt are numerous, have many branches and steep gradients, and flow in narrow, steep V-shaped valleys, but the tributaries in the limestone belt are few and flow in broad, open

valleys little lower than the surrounding country. From the north margin of the quadrangle to Bath the Monocacy flows through the slate belt, and in that distance—about 2 miles—it receives six tributary streams sufficiently large to be represented on the map, whereas in the 12 miles from Bath to Bethlehem through the limestone region it receives only two tributaries sufficiently large to be represented. North of Bethlehem Monocacy Creek shows good examples of intrenched meanders, where the stream is depressed about 100 feet below the surrounding region.

Jordan Creek and its main tributary, Little Lehigh Creek, which enters it from the southwest near its mouth, drains a portion of the Allentown quadrangle and a much larger region to the west. Numerous springs contribute largely to these streams. Bordering limestone cliffs furnish excellent facilities for quarrying which have been utilized. The best example of an entrenched stream meander within the quadrangle is along Jordan Creek near the western margin of the quadrangle.

Saucon Creek, which drains Saucon Valley, in which Hellertown, Friedensville, and other small towns are situated, rises a short distance south of Limeport, outside the quadrangle, and flows northeastward about 15 miles to its junction with the Lehigh at Shimersville. It receives numerous tributary streams from the surrounding higher regions. Throughout the greater part of its course it flows in a broad open valley and has low banks. Limestone bluffs border the stream in only a few places between Bingen and Iron Hill. Although there are numerous bends in Saucon Creek it is a fairly swift stream and has an average gradient of more than 20 feet to the mile.

Bushkill Creek, which flows alternately in the Allentown and Easton quadrangles, has its source in the slate area north of the Allentown quadrangle and flows in a winding course southeastward, southward, and eastward, into Delaware River at Easton. Northwest of Tatamy it is in an open valley, which becomes more constricted in its lower course where it is bordered by steep bluffs that rise 200 feet above the creek.

In certain parts of the quadrangle the drainage bears a close relation to the geology, whereas in other parts it seems to bear little or no relation. The relations depend primarily on the character of the rocks and secondarily on structural features; these conditions determine the number of streams, their location, their direction of flow, the nature of the divides, and the characteristics of the valleys.

The number of streams in the limestone belts is small in comparison with those in the shale and gneiss areas. North of Lehigh River on either side of Monocacy Creek, within the Great Valley, there are areas 4 miles wide which contain no streams. In such regions practically all the rainfall passes through the soil into porous and cavernous limestones. Small sinkholes, few of which are more than 15 feet

deep, are characteristic of the limestone belt of the Great Valley. None of these sinks have caverns open at the surface, yet the water that flows into them passes downward so quickly that the land is marshy in but few places and can be cultivated like other areas. The only exception is the sink $1\frac{3}{4}$ miles east of Brodhead, which contains water. Advantage is taken of these underground lines of drainage in disposal of sewage. Although more than 100,000 people live in the towns of the limestone belts of this quadrangle, only a small proportion of the residences are connected with the municipal sewage systems, which have been built mainly for the purpose of receiving storm water. Holes are sunk into the cavernous limestones, through which the sewage flows probably in well-defined channels. Occasionally stoppage of these channels necessitates the sinking of new holes.

Where soluble rocks, such as limestones, are found in the quadrangle in close association with relatively insoluble rocks, such as the gneisses and shales, the streams usually flow on the more soluble rocks. This is well shown by Saucon Creek, East Branch of Saucon Creek, Durham Creek, which flows through Springtown, and especially by Lehigh River between Allentown and Easton.

Structural features seem to have influenced the location of several streams. Anticlines and synclines seem to have little effect, but faults have undoubtedly determined the location of some streams. Examples of such influence are the upper course of Saucon Creek near Limeport, the lower course of the same stream west of Iron Hill, the small stream half a mile north of Vera Cruz, a small stream that enters Lehigh River opposite the former site of Calypso Island, and the stream that enters Saucon Creek from the east half a mile south of Hellertown.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

General character of the rocks.

The stratigraphy of the Allentown quadrangle is considered only to the extent that seems necessary in order to give a correct appreciation of the economic mineral products contained in the formations. The descriptions, as well as the data on the accompanying map (Pl. II), are generalized. For example, under the general head of gneisses are included igneous and sedimentary gneisses and schists of five different kinds, together with some small intrusions of pegma-

tite, gabbro, and diabase. The Cambrian and Ordovician dolomitic limestones are also separable into three distinct formations. For the consideration of the economic geology however there is no necessity for making these separations.

The rocks of the Allentown quadrangle range in age from the most ancient known to the ones forming today, as shown in the table below. Rocks of many ages are lacking but a number of geologic periods are represented by the strata exposed in the region.

Generalized geologic column of the Allentown quadrangle.

Age		Kinds of rocks	Thickness (feet)
Quaternary	Recent	Alluvium along streams.	0-40
	Pleistocene	Gravels, sands, and boulder clay,	0-40
Triassic		Red shales, sandstones, and conglomerates into which diabase has been intruded.	1,200±
Ordovician		Black shales and slates that locally contain beds of brown sandstone and lenses of limestone (Martinsburg shale).	1,000±
		Black argillaceous limestone (cement rock).	400
		Gray limestones, low in magnesium (cement limestone).	200
Ordovician and Cambrian		Dolomitic limestones.	3,500±
Cambrian		Sandstones and conglomerates, locally metamorphosed into quartzites (Hardyston quartzite).	20-300
Pre-Cambrian		Crystalline graphitic limestone and schists.	150±
		Gneisses of both igneous and sedimentary origin which form the basal complex.	(?)

Pre-Cambrian Gneisses.

The oldest rocks in the region consist of the metamorphic rocks that form the highest hills or mountains of the southern half of the quadrangle. These rocks are light-colored gneisses that are composed mainly of feldspar and quartz together with minor quantities of hornblende, mica, pyroxene, ilmenite, magnetite, and pyrite. Many of them are prominently banded. These rocks, which are the most abundant gneisses of the region, have been greatly decomposed in many places and yield much sand that has been widely used for building. The light-colored gneisses are believed to have been originally igneous.

Another prominent type of gneiss is dark and is composed of plagioclase feldspar, hornblende, and pyroxene, together with small amounts of other minerals. Almost everywhere these rocks are decidedly banded. This type of gneiss is well developed in the region of Hexenkopf Hill, where much of the feldspar has been converted into epidote.

Gneisses of sedimentary origin in which graphite is a prominent constituent, quartz sericite schists, and garnetiferous gneisses also occur in several places.

In many places there are small dikes of pegmatite, most of which are very small and can not be mapped, as the only indication of their presence consists of small pieces of loose pegmatitic rock on the hill slopes. Some small intrusions of diabase and gabbro are also present, the diabase occurring in small masses only.

The gneisses are extremely old and have been subjected to compression and heat so many times that they have had their original characters greatly altered. If the gneisses of sedimentary origin ever contained any fossils all traces of them have been lost in the metamorphic changes which they have undergone.

Although the gneisses are the oldest rocks of the region and form the basement on which the other rocks have been deposited they now appear at the surface in the highest hills, where through folding or faulting they have been more elevated than in the surrounding regions. Other rocks which covered them have been removed by erosion. It is certain that the gneisses underlie all portions of the quadrangle, although in most places they are so far beneath the surface that they have never been reached by drilling.

Pre-Cambrian Crystalline Graphitic Limestone.

In two places in the quadrangle, along Monocacy Creek west of Pine Top and at the margin of the quadrangle southeast of Walters, there are small areas of coarsely crystalline limestones that contain flakes of graphite. These limestones are closely associated with graphitic schists, but their value is so great that they are shown on the map as distinct areas, even though these areas contain some bands of graphite schist. These limestones are similar to the Franklin limestone of New Jersey. They represent calcareous sediments that accumulated in the old pre-Cambrian sea and later were so greatly metamorphosed that they have become far more coarsely crystalline than ordinary marble. The thickness of these rocks has not been determinined, as no drilling has been done in them and all bedding planes have been obliterated during metamorphism, but it is believed that they approximate 150 feet in thickness in this region.

Cambrian Sandstones and Conglomerates.

Overlying the gneisses and cropping out between them and the limestones in all places where there has been no faulting is a series of beds of pebbly conglomerates or fine-grained siliceous sandstones with some interbedded shales, especially in the upper portion of the formation. In many places these rocks have undergone remarkable changes in form, during which they have altered to yellow, taffy-colored chert or, by replacement, to pyrite or limonite ore. Between the gneiss and the sandstones or conglomerates in many places is considerable green pinite rock. The thickness of the formation, which is known as the Hardyston quartzite, ranges from about 20 feet along the north slope of the mountain east of the Freemansburg bridge to about 300 feet near Emaus. Fossils consisting of worm borings have been found in several places.

Cambrian and Ordovician Dolomitic Limestones.

A great thickness of magnesian limestones underlies the valleys and forms the surface rocks of almost half the quadrangle. These rocks have been greatly folded and faulted, so that their structural relations are in many places too complicated to be determined with the present exposures. The limestones are prevailingly high in magnesium carbonate although in places certain strata have so little that they can be used for Portland cement. Near the base the rocks are somewhat thinly bedded, but the upper strata are fairly massive.

By means of fossils and lithologic differences these rocks have been divided into three formations, two Cambrian and one Ordovician. There is little reason for their separation in this bulletin, as throughout the region limestone quarries have been opened at all horizons in these rocks. They have been extensively used for lime, flux, and road metal and to a lesser extent for cement. Deposits of limonite are found in clay pockets in these limestones in many places, and the zinc ores at Friedensville are also contained in them. The clays that result from their decomposition are suitable for brick.

The thickness of these magnesian limestones is difficult of determination on account of their complex structure and the absence of any complete section through them, but it is believed to be approximately 3,500 feet.

Cement Limestone.

A narrow band of high-grade limestones low in magnesium carbonate overlies the magnesian limestones in the northern part of the quadrangle, and one detached area occurs in the western part of Saucon Valley. These limestones are so generally used for cement that they are known as the cement limestones. They are about 200 feet in thickness. Under the heading "Cement limestone" (p. 110) these rocks are fully described.

Cement Rock.

The most important economic deposit of the quadrangle is the black argillaceous limestone known as "cement rock" that extends in a narrow band from Siegfried to Nazareth. The thickness is variable but is about 400 feet as a maximum. As this rock is used solely in the manufacture of cement a full description is given under the heading "Cement rock" (p. 102).

Ordovician Black Shales and Slates (Martinsburg shale).

The northwestern portion of the quadrangle is underlain by black shales and slates of Ordovician age which are described in some detail under the heading "Slate" (p. 130). The rocks were laid down generally as deposits of mud in the Ordovician sea, but sand or calcareous oozes formed in some places. By consolidation the muds formed shales, the deposits of sand became sandstones, and the calcareous oozes became limestones. By intense compression the shales were metamorphosed into the slates which have been quarried in several places in the region. The total thickness of these shales and slates in eastern Pennsylvania is approximately 3,000 feet, but only about one-third of this thickness is represented in the Allentown quadrangle.

Triassic Shales, Sandstones, and Conglomerates.

In the southeastern part of the quadrangle is a considerable area of horizontal or gently inclined beds of generally red shales, sandstones, and conglomerates. These beds were deposited during the Triassic period on rocks formed millions of years previous. The gap between the Ordovician and Triassic rocks in this region indicates that during a long interval of time the region probably stood above sea level and received no deposits or else that all strata formed during this interval were removed by erosion.

Flint Hill, which is included in Bucks, Lehigh, and Northampton counties, best shows the conglomeratic phase of the Triassic; the red shales and sandstones are well developed in the vicinity of Pleasant Valley. Sandstones of this formation have been quarried locally, and traces of copper occur in a few places. The thickness of Triassic strata in this quadrangle is approximately 1,200 feet.

Triassic Diabase.

Compact gray to black diabase intruded within the shales and sandstones is common throughout the belt of Triassic rocks. In this region one area is present east of Coopersburg and another in the extreme southeast corner of the quadrangle. These are the youngest igneous rocks of the region and were poured out millions of years later than those included within the pre-Cambrian gneisses. These rocks furnish material for paving blocks, ballast, and crushed stone for building.

Glacial Deposits.

During the Pleistocene epoch the region was invaded by an ice sheet that came from the northeast and extended over all except a few of the highest hills of the northern and central portions of the quadrangle but did not extend to the southern limits. The ice deposited many cobbles and boulders and worked over the residual clays of the limestones. In places the water resulting from the melting of the ice sorted and deposited thick beds of sand and pebbles which have been worked for sand and gravel, and the reworked clays are serviceable for brick manufacture. The greatest known thickness of the glacial débris is about 140 feet.

Recent Alluvium.

Along the major streams of the region there are some flood-plain deposits that have accumulated during periods of high water. These deposits are chiefly valuable for agriculture, but in a few places some gravel and sand have been obtained from them. In no place are these deposits known to exceed 40 feet in thickness.

GEOLOGIC STRUCTURE.

The gneisses are most complex in their structure, as shown by the relations of the different kinds of rock to one another. Where bedding planes of the old sediments are obliterated, where igneous materials have been intruded and injected into the early rocks at different times, and where a complicated series of folds and faults is present, it is apparent that no satisfactory generalizations can be made, and there is considerable doubt in regard to some of the detailed explanations offered for particular areas.

The Cambrian and Ordovician rocks in general dip to the northwest, so that younger and younger rocks are crossed in traveling in that direction from the gneiss hills. The Cambrian sandstones and conglomerates disappear by dipping to the northwest beneath the Cambrian and Ordovician magnesian limestones, which in turn disappear beneath the cement limestone, and the cement limestone dips under the cement rock, whereas the Ordovician shales and slates and the interbedded sandstones and limestones rest on the cement rock. Numerous symmetric and unsymmetric and overturned folds and both normal and thrust faults complicate the structure, so that the generalizations given can not be locally employed. J. P. Lesley[1] describes this region in the following passage:

> It seems a very easy matter to obtain the knowledge which we want in so open, well-formed, almost level valley, bounded on one side by a mountain faced by a well-known rock underlying the limestone (Potsdam S. S. No. I) and on the other by hill slopes of unmistakable overlying slates (Hudson River, No. III). But what seems a facility turns out to be the principal difficulty. What seems so smooth and regular a surface conceals one of the most contorted, twisted, fractured cleft, plicated, complicated, and even overturned set of subsoil rocks in the world.

[1] Pennsylvania Second Geol. Survey, Rept. D. p. 59, Harrisburg, 1875.

The Triassic sandstones were laid down after the great folding and faulting of the underlying rocks had taken place and have a much more simple structure. Low angles of dip prevail throughout the region.

The glacial deposits are irregular in this quadrangle. They are thickest in the limestone areas and practically absent in the gneiss hills. In places the glacial deposits have been removed by erosion, so that they appear now in patches.

ECONOMIC GEOLOGY.

IRON ORES.

Although at the present time the iron ores of the Allentown quadrangle are not being worked, they have been of the greatest importance in the economic development of the region. For nearly 100 years the mining of iron was an extensive industry in this section and only within the last few years has it ceased entirely. The manufacture of iron and steel, which was started during the period when the iron mines were in active operation, still continues to be one of the principal industries of the region, even though all the ore used now comes from Michigan, Minnesota, Wisconsin, New York, New Jersey, Cuba, Chile, Sweden, Greece, and other places. The closing of the mines is due to several causes, among which the most important is the improvement of transportation facilities, which permits higher-grade ores from other regions that can be procured in great quantities at low cost to compete with the local ores. Though the ore in some mines was practically exhausted this condition does not apply to the greater number of the deposits.

Historical Sketch.

The history of the earliest development of the iron industry in eastern Pennsylvania is somewhat obscure. All records seem to indicate that the first iron ores used were the magnetite ores of Durham, about 3 miles east of the Allentown quadrangle. These deposits seem to have been guarded by the Indians as early as 1698, which probably means that the early Dutch and Swedish traders had recognized their value. A tract of 5,000 acres containing the Durham iron deposits was part of William Penn's purchase from the Indians and was surveyed by Jacob Taylor in 1701. There was a settlement on this tract as early as 1723, and it may be inferred that the deposits were operated at that date, although the first definite information obtainable is that a furnace was erected at Durham in 1727 and put in blast in the spring of 1728. With iron furnaces in operation so near the borders of the Allentown quadrangle it is probable that some

magnetite may have been mined in the hills in the eastern portion of the quadrangle, where ore of the same kind occurs in small quantities.

A bloomery is said to have been built near Jacobsburg, a few miles north of Nazareth, in 1805 and another one in 1809, and both of them used local limonite ores, some of which probably came from mines within the Allentown quadrangle. In 1824 and 1825 Mather S. Henry erected a blast furnace north of Nazareth, which was put into operation in May, 1825. He states that "the principal part of the ore used was the columnar or pipe species of hematite ore of Lower Mount Bethel Township, as also the brown hematite from Williams and Hanover townships in Northampton, and Whitehall in Lehigh counties[1]." This is the first definite information regarding the use of the iron ores of the Allentown quadrangle.

Between 1830 and 1840 many limonite ore mines were worked along the south side of Lehigh River between Easton and Bethlehem and in the vicinity of Emaus. The condition of the industry in the summer of 1840 is thus described:[2]

> About three miles westward from South Easton, a mine has been opened, at Jacob Woodring's, in a hollow between two spurs of the primary chain. It was not wrought at the time of our examination. The shaft here is said to be 90 feet deep, passing through diluvium and clay for 55 feet, before any ore was found. The ore is moderately rich. but contains some manganese. The limestone shows itself on the surface, about 300 yards north of the ore. Westward of these localities, surface signs of ore are abundant, as at Ihrie's and Brotzman's, half a mile south of the Lehigh. At Brotzman's. where some manganese is associated with the ore. the diggings were made probably too high in the side of the hill, being apparently outside of the edge of the limestone. The ore here is rough and sandy, and contains compact black oxide of manganese in some abundance. A little hill, further west, on the same farm, lying within the limestone, shows a much better ore on the surface. On Richards' farm, in the same range as Brotzman's, but farther west, surface ore is quite abundant, some of it being fibrous hematite. The next farm westward, presents the same indications. At the period of our exploration, the Lehigh Crane Iron company, whose works are situated on the Lehigh, three miles above Allentown, were about to commence some shafts on Richards' farm. They have since, it is said, purchased Ihrie's, so that it is now probable that the ores of this neighborhood will be well investigated. Above Richards', the primary formation approaching the river, cuts out the limestone, and consequently, the ore. But the limestone again showing itself higher up the river, a little ore has been dug above Bethlehem bridge, where, however, it is probably exhausted. Pursuing the same line to the S. W., we find an iron mine, (Swartz's), at present neglected, about three-fourths of a mile S. W. of Emaus. At this spot there is only one mine hole, about forty feet deep. Smelted alone, this ore made a cold short iron, and was therefore usually mingled with other ores, principally with that from Breinig's mine. In some of the specimens found here, no manganese could be detected, though some of the ore has a manganesian aspect. Its geological position is in diluvium, lying near the border of the limestone.

The local iron industry received a great impetus in 1840 owing to the successful smelting of the iron ore by the use of anthracite coal. Before 1840 anthracite had been used in place of charcoal, but not until 1840, when the Lehigh Iron Co. (later changed to the Crane Iron Co.) started its first blast furnace at Catasauqua, was the ex-

[1]Henry, M. S., History of the Lehigh Valley, p. 165, 1860.
[2]Rogers, H. D., Fifth annual report on the geological survey of Pennsylvania, pp. 42-43, 1841.

periment entirely successful. To furnish ore for the furnace several iron mines in the vicinity were opened. The first of these was Rice's or Henry Hoch's, near Shoenersville. Two other mines near by, known as Goetz's and Daniel's, were opened about the same time. The Crane Iron Co. (now owned and operated by the Replogle Steel Co.) in its furnace at Catasauqua has probably used more local ores than any other company in this section.

Within the next decade iron furnaces became numerous along Lehigh River from Coplay to Easton and most of them were run mainly if not entirely on local limonite ores (usually called brown hematite by miners and furnacemen), supplemented at some furnaces by magnetite ore from New Jersey. There is scarcely a settlement along Lehigh River within the Allentown quadrangle that has not at some time had blast furnaces in operation.

The Lehigh Valley Iron Co. (later the Coplay Iron Co.) erected a furnace at Coplay in 1854 which continued to operate until 1873, producing about 6,000 tons of pig iron a year.

In 1854 the Thomas Iron Co. was organized and shortly began the erection of two blast furnaces at Hokendauqua. Two other furnaces were subsequently built. Some of these furnaces have been in operation almost continuously ever since 1855. New Jersey and Lake Superior ores have gradually replaced the local limonite ores.

The Allentown Iron Co. erected its first furnace in Allentown in 1846 and other furnaces in 1847, 1852, 1855, and 1872. The site of the old furnaces was later occupied by a small charcoal furnace. The company obtained a large portion of its ore from the northwest slope of South Mountain northeast of Emaus.

For 37 years the Lehigh Iron Co. operated two furnaces at the base of the mountain half a mile below Allentown along the Lehigh Valley Railroad. The first furnace was started in 1869 and the second in 1872. Both were later rebuilt. They were run on local ores for many years, but afterward Lake Superior, Adirondack, and New Jersey ores were substituted. These furnaces were closed in 1906 and dismantled in 1909.

In 1857 the Saucona Iron Co. was organized to work the Gangewere mine in the Saucon Valley and to erect a blast furnace. The first plan was to build the furnace at the mine, but it was later decided to build the furnace at South Bethlehem, and the name of the company was changed to the Bethlehem Rolling Mills & Iron Co. Owing to financial difficulties the erection of the furnace was not started until July, 1861, and about that time the name of the company was changed to the Bethlehem Iron Co. On account of the Civil War it was not until January, 1863, that the furnace was completed and put into operation. In 1868 the Northampton Iron Co., which owned large iron mines in the Saucon Valley and which was building a furnace

near Freemansburg, was merged with the Bethlehem Iron Co. For many years a large part of the ore used came from the Saucon Valley. At present the company, which is now the Bethlehem Steel Co., uses no local ores.

The next furnace on Lehigh River below those described was that of the Coleraine Iron Co., located at Redington, which was organized by W. T. Carter & Co., of Philadelphia, in 1869. Two furnaces were operated for several years but are now in ruins. The company owned and operated four mines in Northampton County, three in Lehigh County, and three in Berks County.

Just east of the boundary of the Allentown quadrangle along Lehigh River is the Keystone furnace, which for years obtained its ore from mines near by. The building of the furnace was started in June, 1873, and it was first put in blast April 17, 1876. On April 1, 1882, it was purchased by the Thomas Iron Co., which operated it until recently.

Two iron companies have operated furnaces in the Saucon Valley. The largest operator was the Saucon Iron Co., which built two furnaces at Hellertown, one of which was put in blast on March 25, 1868, and the other on May 25, 1870. The company owned several iron mines near Hellertown and Bingen and a few miles of railroad connecting some of the mines with the North Pennsylvania, Philadelphia & Reading Railroad. The company's properties were sold to the Thomas Iron Co., on December 13, 1884, and the furnaces have been in operation almost continuously ever since. Local limonite mines furnished much of the ore until a few years ago.

The North Pennsylvania Iron Co. was chartered in April, 1869, and proceeded to build a furnace at Bingen. The furnace was first blown in on June 1, 1871. On July 8, 1872, it was damaged by an explosion, and operations ceased until October 15 of the same year. After a few weeks the stack burst, and the furnace remained idle until January 25, 1873. It then worked with little interruption until April 8, 1875, but is now in ruins. The largest amount of pig iron manufactured in one year was 10,777 tons in 1874. Nearly all the ore used came from limonite mines near Bingen.

The Reading Iron Co. operates a furnace at Emaus, which has been in operation since about 1880. The first ore used was entirely local and was obtained from the magnetite mines near Vera Cruz and the limonite mines in the vicinity of Emaus. In recent years the ore has come mainly from the Lake Superior region and Sweden.

On a map of the Durham and Reading Hills prepared by the Second Geological Survey of Pennsylvania a furnace is shown along the road about 1 mile east of Vera Cruz station, but no information in regard to it has been obtained. If there ever was a furnace in that locality it must have been operated for a short time only.

Many of the furnace companies also owned and operated mines. However, most of the mines of the region were owned by individuals or by mining companies, and these produced the greater part of the ore used in the quadrangle. Some of these mines were worked for short periods only and were of little consequence, but others were operated for 40 or 50 years and yielded a large tonnage. Altogether 152 mines are shown on the map, and no doubt some of the smaller ones are not shown, as the old workings have now been filled and all record of their existence has been lost. Most of these mines supplied limonite ore (brown hematite), although a number of magnetite mines were worked, especially in the mountains between Emaus and Vera Cruz.

The only iron mine in operation in the region within the last ten years is a magnetite mine on the south slope of South Mountain north of Vera Cruz and the only furnaces in blast are using ores shipped from distant points. The furnaces that remain are at Hokendauqua, Catasauqua, Bethlehem, Hellertown, and Emaus. Many persons still living recall the time when the roads in all directions were occasionally rendered almost impassable on account of the heavy loads of ore hauled over them to the furnaces from the local mines. In places the roads were occupied by long lines of ore wagons, and mining was one of the principal occupations. At present the old mine holes that are filled with water serve as swimming holes for the boys of the vicinity or furnish excellent places for raising bullfrogs or fish. However, interest in the mining of iron ore has not been lost, prospecting for good deposits is still being carried on from time to time, and many persons are confidently looking forward to the revival of mining activity in the region.

Brown Iron Ores (Limonite).

The iron ores of the Allentown quadrangle belong to two classes—the brown (limonite) and gray (carbonate) ores of the Cambrian and Ordovician formations and the magnetite ores of the pre-Cambrian gneisses. The two classes are sharply separated in practically all their characteristics, such as kind of ore, method of occurrence, and origin.

The brown ores (limonite) of the region are generally known locally as brown hematite. There is some justification for this usage, as some of the ore is decidedly red on account of the admixture of goethite and turgite and in places might be confused with hematite. The limonite ores are separable into two classes, which have been called "mountain ores" and "valley ores." Both classes are well represented in this quadrangle. The mountain ores are found along the slopes of South Mountain and in some of the narrow valleys east of the Saucon Valley and are included within the Cambrian quartzite areas; the valley ores occur in the broad valleys in areas of Cambian and Ordovician limestones.

Distribution.

Mountain ores. The mountain ores are confined to the areas of Cambrian quartzite but do not occur in all places where that formation is present. Most of the mountain ore mines of the quadrangle are in a belt along the northwest slope of South Mountain that extends from the western margin of the quadrangle to a point some distance beyond Mountainville, and one mine is in the same line near the place where this range joins the ridge extending from Allentown to Bethlehem. Mines in these ores have also been worked in the short, steep-sided valleys southeast, east, and northeast of Hellertown. A few mines are more or less isolated, such as the mine a quarter of a mile southwest of Limeport, two mines about 1 mile west of Center Valley, one half a mile south of Springtown, and one at the extreme east margin of the quadrangle about half a mile south of Lehigh River.

Mines are numerous in certain areas of the Cambrian quartzite but are lacking in other regions where the formation is equally well developed, such as the slopes of the mountain that face Lehigh River. The metamorphic changes which the formation has undergone locally since its deposition have determined the places where ore has been deposited. In the regions where the ore deposits are present many of the original sandstone strata have been changed into jasperoid rocks, although certain conglomeratic strata remain practically unchanged, but in places where ore deposits are absent the formation is composed entirely of ordinary sandstones and conglomerates. It is therefore considered useless to prospect for iron ore of this type in areas where the irregular masses of yellow to red jasperoid rocks are absent in the soils.

Valley ores. The limonite ores of the limestones are extremely irregular in their distribution. The map shows one belt of iron mines that extends in an east by north direction through Shoenersville and Hanoverville to Hollo and another in the Saucon Valley that extends about 3 miles west from Friedensville. Many other mines of the limestone regions, however, are not included in either of these belts.

There seems to be some relation between the structural features of the rocks and the location of the ore deposits, for as a rule the largest deposits of ore are found in places where the limestones have been closely folded or faulted. As the rocks are likely to be much more shattered at the crests of closely folded and eroded anticlines such places should be more favorable for ore deposition, and the investigations in this region indicate a relationship of that kind. In general, those places in the limestones where the underground waters have collected and flowed with greater freedom are the places where the ore was deposited in largest amounts. Miners frequently remark upon the observed connection of underground watercourses and the

limonite deposits. As a rule, throughout the limestone regions good wells can be procured in few places at depths less than 200 feet, and yet few good iron mines have been opened where the volume of water encountered at depths of 100 feet or even less was not an obstacle to the development.

Limonite deposits are not found in the valleys of the main streams but only in those places where recent erosion has been of small extent. They are more common in local depressions in the general upland surface in regions where sink-hole topography is noticeable. As the glacial deposits are usually thicker over the ore deposits than in the surrounding region it is probable that depression existed there before the glacial epoch and glacial deposition was probably greater there than in the higher regions near by.

Occurrence.

All the limonite ore deposits of the Allentown quadrangle are surficial. They are irregular in extent and either occupy pockets in the underlying rocks as much as 100 feet or more in diameter, or follow certain strata that more readily yielded to solution or replacement. In the belt of iron mines along the slope of South Mountain northeast of Emaus certain strata were converted into iron ore more or less completely for a distance of about half a mile, and the ore bodies are consequently parallel to the adjoining strata both in dip and strike. In other places, however, the ore formed irregular masses which bear little relation to the structure of the surrounding rocks, so far as can be determined. Usually, however, the greatest diameter of the ore body is parallel to the strike of the inclosing strata.

The position of the mountain ores near the base of the mountains formed of gneiss causes them in most places to have a surface cover of float rock from the higher ground, and consequently the ore appears at the surface in but few places. This cover may be so deep that the ore can be worked only through shafts, although several of the mines near Emaus and Hellertown were worked by open cuts in the upper levels.

In some places the valley ores are concealed by deep deposits of glacial material that render their discovery difficult, but most of the bodies of ore thus far worked were located by the float ore in the soil. Good ore in many mines was reached within a few feet below the surface. In some freshly plowed fields the soil in the vicinity of a body of limonite ore is of a rich brown color that can be easily distinguished at a distance. Most of the ore bodies in the limestone

valleys have been discovered by sinking test pits in places where the soil was deeply colored and pieces of float ore were abundant. Bodies of workable ore have also been discovered by sinking test pits along the line of known deposits or in the vicinity of sink holes.

The ore has been found as much as 175 feet below the surface, which was approximately the maximum depth of the mountain ore mines, owing to the difficulty of keeping them free from water and also owing to the tendency for the shafts and drifts to be closed or rendered dangerous on account of the squeezing action of the clay associated with the deposits, which slowly moved downhill when saturated with water. It is probable that few of the bodies of limonite ore extend much below the ground-water level and thus that they scarcely exceed a maximum depth of 300 feet, which is much deeper than any of the mines of the region. In many of the valley-ore mines the limonite occupied shallow basins in the limestones and solid limestone was found at depths less than 50 feet. Rock in place is now exposed in many of the old limonite pits. In the mines of mountain ore the ore became leaner or changed to ore high in sulphur in lower levels but still continued to the greatest depths reached.

The iron ore is almost invariably associated with quantities of white, yellow, or buish-black clay formed by the decomposition of shaly strata which are interbedded with Cambrian sandstones and quartzites and the Cambrian and Ordovician limestones. In addition to the clay, masses of jasperoid quartzite are commonly encountered in the mountain-ore mines, and small and large rounded segregations of black chert occur in the valley ores. The fragments of jasper represent portions of the original Cambrian quartzite that have undergone less alteration.

Within the clay the iron ore occurs either in the form of isolated masses or in rather definite veins that have a maximum width of 40 feet. Even in the best ore bodies considerable clay and ocher are present, ranging from one-third to one-fourth of the material removed from the mine. In the average mine the clay washed from the ore constituted from 50 to 75 per cent of the product. The ore in the veins is invariably cavernous and contains considerable clay within the cavities.

Yellow ocher is almost everywhere associated with the ore, as would be expected, for ocher is an intermediate product between the clay and the iron ore. In the ocher the limonite has not been segregated but occurs in the form of finely disseminated particles intimately mixed with the clay.

Physical Character.

The limonite ore is found in several different forms some of which have received distinctive names by the miners, such as bombshell or pot ore, pipe ore, and wash ore.

The bombshell, or pot ore, consists of more or less spherical masses of limonite that range in diameter from 1 inch to 2 feet. They are geodes of limonite, and many of them are hollow or filled with water whereas others are fairly well filled with white or drab clay or fine white to pink sand. The interior of these geodes almost invariably presents a black lustrous botryoidal surface, which in some specimens is markedly iridescent. The dark color of the interior suggests the presence of considerable manganese, and analyses commonly show this metal to be present. Tiny stalactites of limonite occur in many of the geodes. The walls of the bombshells range from considerably less than an inch up to an inch or more in thickness and in most specimens show a fibrous radiating structure in the inner layers. Some of the geodes contain sand grains firmly cemented by the iron oxide, but others are practically free from any siliceous particles that can be detected by the eye. In general, the bombshell ore is the highest grade ore obtained and can be readily freed from any adhering clay by washing. Many of the geodes consist largely of iron carbonate (siderite), and in a few mines the bombshell ore is called carbonate ore. Invariably, however, limonite also seems to be present, especially in the inner layers. The carbonate bombshell ore is gray when mined but later becomes brown, as the carbonate changes to limonite on exposure. Some geodes have been found in which the stratification of the original sandstone or limestone is preserved in the inclosing walls.

Closely related to the bombshell ore are the large irregular masses of cellnlar material that form the bulk of the limonite ores. These masses are from a few inches to 10 feet or even more in diameter and consist of a network of thin partitions of limonite running in every direction. The cavities are usually small, as a rule not more than a few inches in extreme length, are exceedingly irregular in shape, and are commonly filled with an ocherous clay. The walls of the cavities are coated with a firmly cemented layer of the ocher. The character of this ore renders it possible for the miners to break the large masses readily with pick and sledge.

Some of the mountain ores occur as masses of porous limonite roughly arranged in parallel layers and resemble in structure pieces of rotten wood. The layers probably represent the stratification lines of the original rocks. Tiny stalactites of limonite are abundant between the layers.

Small pieces of cellular ore in which the cavities are rectangular in shape are occasionally found. These specimens represent the segregation of limonite in joints of the original rock, the partial replacement of the original rock, and the subsequent removal of the remainder through solution. Some of the longer tubelike masses are called pipe ore, although true pipe ore is somewhat different. In some places the original rock remains surrounded by a shell of limonite. In the mountain-ore mines pieces of limonite inclosing sandstone are not uncommon.

In many places the original sandstone of the mountain ores seems to have been broken into angular fragments, probably owing to the contraction of the mass as it changed to jasper, which usually preceded the formation of the ore. These angular fragments have later been cemented by limonite that was precipitated in the cavities and forms a limonite breccia. In many specimens fragments of sandstone or jasper have themselves later been replaced by limonite. In ore of this kind small particles of secondary vein quartz are more common than in the other kinds of ore, although quartz is not common in any of the limonite ores. The secondary quartz shows that part of the siliceous material removed by the solution of the original rock was precipitated in the cavities of the iron ore.

In the valley-ore mines tubes of limonite which inclose more or less sand are common. This variety is known as "pipe ore" and was the principal ore mined in many places. The largest tubes are a foot in diameter, although most of them range from 1 to 2 inches. Pieces more than 8 inches long are rare but as the pipes are invariably broken at each end they may have been originally several feet long.

Fragments of limonite in the form of irregular particles or plates are invariably present in large quantities. They represent broken pieces of all the kinds of ore that have been described. As the rock disintegrates and clay and iron ore are formed there is a tendency for the entire mass to move down the slopes, which results in the breaking of the more fragile pieces of ore. The loss in bulk that takes place as the rock undergoes changes in composition also permits the downward settling of the material and the breaking of many of the masses of ore. The larger pieces of the fragmental ore are recovered in the washers, but the finer ones are lost. Ore of this kind is known as "wash ore."

Composition.

Minerals associated with the ores.— The composition of the limonite ores is extremely variable and depends largely on the physical character of the material. The presence of certain minerals closely associated with the limonite also determines the composition. The impurities in the ore comprise only a small number of minerals, principally quartz, jasper, clay (kaolin), pyrite, pyrolusite, and wavellite.

Siliceous matter of different kinds can be detected in almost all the mountain ores. In some places it represents the fine grains of sand of the original sandstones or sandy limestones, in others secondary chert or jasper, and in still others vein quartz. Clay fills many of the cavities in the ore, and much of it is not removed in passing through the log washers. Very small particles of pyrite can be seen with the naked eye in some specimens, particularly in the ore from the lower levels of certain mines.

Pyrolusite is intimately associated with the limonite and is generally detected by the dark color of the ore. Occasionally dendritic crystals of pyrolusite forming a thin cover to the limonite are found, but usually the pyrolusite occurs as the inner layer of the bombshell ore. In general the mountain ore contains a higher percentage of manganese than the valley ore. A mass of crystalline pyrolusite from the Wharton mine of the Thomas Iron Co., 2 miles east of Hellertown, yielded on analysis in the laboratory of the company the following results:

Analyses of pyrolusite from Wharton mine of Thomas Iron Co., 2 miles east of Hellertown, Pa.

Mn	52.72
Fe	.868
SiO_2	.46
P	.046

Most of the phosphorus in the ore is probably contained as aluminous and iron phosphates, such as wavellite [$(AlOH)_3 . (PO_4)_2 . 5H_2O$] and cacoxenite [$FePO_4 . Fe(OH)_3 . 4\frac{1}{2}H_2O$]. In the iron mine three-quarters of a mile southeast of Hellertown fine, delicate white radiating crystals of wavellite occur within the cavities of the limonite ore. At the same locality fine tufts of golden-yellow crystals of cacoxenite are present in the small crevices of the ore and also small quantities of beraunite [$Fe_3(OH)_3(PO_4)2 . 2\frac{1}{2}H_2O$]. In most of the ores, however, no phosphorus minerals can be seen, although analyses show that some are present.

Mountain ores. Although the sulphur is almost invariably low some mines have been worked in which a large amount of pyrite is

present in the lower levels. This is especially true in the mines along the northwest slope of Lehigh Mountain between Emaus and Mountainville. It is probable that deeper workings may show an increase of pyrite in almost all the mines, but the decrease in the content of iron and the increased expense of mining has prevented the exploration of the lower portions of the ore bodies in most places. The examination of hundreds of analyses made by the chemists of the Thomas Iron Co., the Bethlehem Steel Co., and the Crane Iron Co. shows that the mountain ores average about 40 per cent iron, 20 per cent silica, 0.40 per cent phosphorus, 0.20 per cent sulphur, and 3.26 per cent manganese. The iron content ranges from 32 to 54 per cent. Very little ore was used in which the ore contained less than 36 per cent iron, and a few mines have furnished much ore that ran as high as 50 per cent iron. The ores are characterized by a high percentage of silica, ranging from 15 to 30 per cent. The phosphorus is usually too high for Bessemer steel; in much of the ore it runs up to approximately 1 per cent.

Perhaps the most distinctive feature of the mountain ores is the high content of manganese, which ranges from 2 to 4 per cent in most of the mines but may run as high as 15 per cent in places, and pieces of practically pure pyrolusite are occasionally found. For this reason in making basic iron the mountain ores have always been in demand by the furnaces.

Analyses of limonite mountain ores of Allentown quadrangle, Pa.

	1	2	3	4	5	6	7	8	9
Fe	35.63	44.16	41.19	31.94	37.15	39.25	36.50	47.20	48.80
SiO_2	28.12	19.14			17.39				
P	.221	.377	.939	.927		.149	.547	.075	.196
S	.015					.029	.107	.039	.014
Mn	15.305	2.18		2.48	7.73	5.512	1.325	2.707	.900
Moisture		6.78		7.53	6.63				11.340
Al_2O_3		4.21		6.58					2.388
Insoluble residue						21.880	31.215	14.980	13.915
MgO									.317
CaO									.300

1. Lehigh Mining Co., north slope of Lehigh (South) Mountain between Emaus and Hellertown; average of 4 samples. Thomas Iron Co.
2. Wharton mine; average of large number of analyses. Thomas Iron Co.
3. Bachman mine; average of 6 samples. Thomas Iron Co.
4. Koch mine; average of 6 samples. Thomas Iron Co.
5. Emery or Beatty mine; average of 6 samples. Thomas Iron Co.
6. Keck & Ritters mine, 2 miles east of Emaus. Genth.
7. Trexler & Kline's mine, three-fourths mile east of Emaus. Genth.
8. Jesse Kline's mine, one-half mile east of Emaus. Genth.
9. Central Seam's mine, one and one-half miles east of Emaus. Genth.

Valley ores. The valley ores differ somewhat in composition from the mountain ores. These differences are mainly in the greater amount of silica and manganese in the mountain ores and the greater amount of magnesia and phosphorus in the valley ores. Most of the ores after washing to remove the bulk of the loose clay averaged

slightly more than 40 per cent metallic iron and ranged approximately from 35 to 55 per cent. The analyses shown in the following table are of valley ores from the Saucon Valley.[3]

Analyses of limonite valley ores of Allentown quadrangle.

[A. S. McCreath, analyst.]

	1	2	3	4
Sesquioxide of iron	64.428	75.714	68.785	47.000
Sesquioxide of manganese	.982	.228	.207	.889
Sesquioxide of cobalt	.040	.010	.020	.080
Alumina	2.108	1.421	2.974	3.696
Lime	.170	.160	.120	.100
Magnesia	.288	.288	.288	.418
Sulphuric acid	.032	.447	.612	.062
Phosphoric acid	1.104	1.175	.941	.584
Water	11.374	12.724	18.866	8.622
Insoluble residue	19.760	7.790	13.310	38.940
	100.286	99.957	100.123	100.391
Metallic iron	45.100	53.000	48.150	32.900
Metallic manganese	.684	.159	.144	.619
Sulphur	.013	.179	.245	.025
Phosphorus	.482	.513	.411	.255

1. Lump and wash ore from David Schneider's mine, 3 miles southwest of Friedensville.
2. Pipe ore from Kurtz's mine near Friedensville.
3. Lump and wash ore from Morgan Mory's mine near Friedensville.
4. Lump and wash ore from G. & W. Mory's mine near Friedensville.

Origin.

Processes of formation.—Although the limonite iron ores of the Appalachian region have been discussed in hundreds of articles, there is still no entirely satisfactory explanation of their origin. Many investigators have shown a tendency to regard all of them as having a similar origin, which is an incorrect view. Even in a single mine evidence can sometimes be obtained to prove that limonite has been formed by the oxidation of pyrite, by the oxidation and hydration of siderite, by the replacement of limestone or sandstone, by the segregation of particles of disseminated limonite, or by precipitation in open fissures or other cavities. Under such conditions it is obvious that a theory which attributes the origin of these ores to one process of formation is not sufficient even for certain single deposits and is entirely inadequate for universal application.

The limonite ores are commonly known as "residuary iron ores" and are supposed by many investigators to represent the insoluble oxidized particles of iron that were originally present in limestones

[3]Pennsylvania Second Geol. Survey, Rep. MM, p. 217, 1879.

or shales in the form of carbonates or sulphides and were left as a residuum when the mass of the country rock was removed by solution. Such an explanation, however, disregards the concentration of the ores in somewhat veinlike ore bodies. The particles of limonite have not merely been left as a relatively insoluble residuum on the removal of the inclosing rock, but instead in the main they have been transported in solution and precipitated in more or less concentrated form in the clays that are plainly of residuary origin. For these reasons the term "residuary limonite ores" is likely to be misleading and is only appropriate if the ores are considered to represent materials that were once distributed through a great thickness of rocks now removed by erosion. The ores themselves have also been dissolved, transported, and precipitated, perhaps several times.

In the discussion of the origin of the brown iron ores three stages should be considered--the original source of the iron, the primary segregation, and the secondary concentration.

Original source of the iron.—The iron of the brown iron ores was probably present in the form of pyrite, magnetite, or some ferromagnesian silicate, original constituents of the igneous rocks that underlie all the sedimentary strata in which the bodies of ore now occur. When the Cambrian and Ordovician sandstones, limestones, and shales were deposited in the shallow waters of the Appalachian sea both pyrite and siderite were precipitated from solution to form part of these sedimentary strata. Consequently all the rocks of the region—gneisses, sandstones, limestones, and shales—have contributed material for the formation of the ore bodies. Not only have the rocks now present in the region yielded iron for these deposits, but much was also derived from a great thickness of rocks which once overlay the present strata and were removed in the long period during which the Appalachian province has been subjected to erosion. At least 10,000 feet of strata have been removed by erosion from the region since Ordovician time, and though no doubt most of the iron of these rocks was carried away, a considerable portion was dissolved and precipitated in the underlying rocks.

Primary segregation of the iron.—The most striking feature of the occurrence of limonite deposits in the limestones is their relation to channels of underground drainage. The abundance of water was a serious obstacle in the operation of almost every valley-ore mine that was more than 50 feet in depth though elsewhere in the limestone valleys wells must be sunk much deeper in order to procure enough water for household use. As these water channels are formed by the fractures in the rocks which were produced during the great earth disturbances at the ends of the Ordovician and Carboniferous periods, it is reasonably certain that the ground water has been flowing through them for millions of years.

The mountain ores are also found in regions where the rocks have been fractured and afford free passage for the ground water circulation. In every place in the region where the mountain ores have been mined the Cambrian sandstones have been largely altered to jasper or chert. The metamorphism is believed to have taken place mainly at the end of the Ordovican period, when the region was subjected to intense dynamic forces that resulted in the intricate folding and faulting now so well exhibited. Post-Carboniferous movements also have been effective in producing the complicated structure. Meteoric waters that passed through the deformed strata were undoubtedly heated above normal temperature and their dissolving power was increased. The grains of quartz of the sandstones were dissolved, and the material was later precipitated in the cryptocrystalline form. In the replacement there was a considerable shrinkage, as is shown by the numerous contraction cracks or brecciated form of the jasperoid rock. In some places the cavities were subsequently filled with quartz or jasper which made the rock almost as compact as it was originally, but in general the jasperoid rock is extremely porous.

The first step in the formation of the ore was the segregation of the iron that was disseminated through the gneisses, sandstones, limestones, and shales of the region in the form of pyrite and siderite. Meteoric waters that passed downward through the strata dissolved the pyrite and siderite. When these solutions reached the shattered areas in the limestones or the zones of porous jasperoid rock that rested on gneisses the water in many places ascended, just at the present time the deep-seated waters of the region rise to the surface along fault or fracture zones. Even in the areas where only limestones are present flowing wells have been obtained at depths of 750 feet, which shows the tendency of the deeper waters of the region to rise under artesian pressure when a passageway is provided.

In the Cambrian sandstones the ascending solutions precipitated pyrite in part as a filling of previously existed cavities and in part as a metasomatic replacement of the jasperoid rock or the shales that were interbedded with the quartzite, especially in the upper part of the formation. So few mines have been worked to the depth where the pyrite ore still persists that little evidence of the manner of deposition of the pyrite is available. Some specimens obtained from one of the mines about halfway between Emaus and Mountainville indicate an almost complete replacement of the quartzite, but it is doubtful whether these are typical. Instead, it is probable that the substitution of the pyrite for the jasper and shales was irregular and variable. One of the chief supports of the view that ascending waters have caused the segregation of the pyrite is furnished by the depth to which the pyrite extends. It is now found at the greatest depths explored, far below ground-water level. The level of ground

water has fallen as the valleys have been deepened by erosion, and therefore it is probable that part of the pyrite was formed at much greater depths than would be possible if it were segregated by descending waters. Besides, in the almost complete absence of any organic matter in the Cambrian quartzite it is difficult to see how the precipitation of the pyrite could have been accomplished by descending waters rich in oxygen, in which the temperature and pressure would have continually been on the increase. Decrease of temperature and relief of pressure were probably the dominant factors in the precipitation of the pyrite from the ascending solutions.

In regard to the valley ores, the primary segregation of pyrite by artesian waters as the first stage in the formation of the present ore bodies is less definitely known. The massive pyrite found in the lower levels of the Friedensville zinc mines and the increase of pyrite with depth in many of the limonite valley ore mines indicate the presence of pyrite beneath the brown ores in certain places, although the data are too meager to warrant the conclusion that a zone of pyrite is everywhere present. In a brown iron ore mine near Breinigsville, in the Slatington quadrangle enough pyrite was obtained in the lower levels to be profitably marketed. In most places, however, the mines were not worked deep enough to determine whether pyrite commonly underlies the limonite ores or not. The increase of sulphur in the ore caused some mines to become unprofitable, but the excess of water and the slumping of the clay banks were the principal causes for other mines closing before a zone of pyrite was reached. Nevertheless the facts at hand warrant the conclusion that many of the great limonite deposits of the region are underlain by considerable pyrite, which, however, may be and probably is as a rule too greatly disseminated to be of any economic importance.

Part of the precipitation took place in open fissures in the limestones, but much of it was in the nature of replacement of the rocks that constitute the walls of the fissures. This feature was plainly shown in the Friedensville zinc mines, where the limestones were extensively replaced by pyrite.

The brown iron ores are invariably associated with a large amount of clay representing the residuum of shaly strata interbedded with the limestones and sandstones. These impervious shaly beds undoubtedly to a large degree furnished favorable conditions for the primary segregation of the pyrite through assisting the concentrated flow of the mineralized underground waters, and the places where the shaly strata were present were therefore most suitable for the deposition of the minerals that were carried in solution.

The presence of pyrite in the lower workings in considerable quantities seems to indicate that the ores cannot have been formed

entirely by descending waters that have brought the iron in solution to these places, as is generally supposed. The abundance of pyrite invalidates the explanation of other writers who believed that the ores deposited in the Cambrian sea as limonites or that they represent the oxidation in place of iron carbonate ores that were deposited as marine precipitates. There are likewise valid objections to the explanation proposed by Chance,[4] who believes that the ores are gossan deposits that were formed by the oxidation of pyrite which was "a mechanically transported sediment, derived from the erosion of older eruptives." On account of the instability of pyrite it could hardly be liberated from igneous rocks through the decomposition of some of the constituent minerals without itself being oxidized, and the situation of most if not all of the ore bodies in regions where the rocks have been greatly shattered might also be used as an argument against this view.

Whether the carbonate ores were formed during the primary mineralization can not be definitely determined without additional information. The carbonate ores are found in the lower levels of both the valley ore and the mountain-ore mines in association with the limonite, but data are lacking as to their association with the underlying pyrite. Where the ascending iron-bearing solutions came into contact with limestones or encountered carbonate waters from the limestones, it would be natural to expect the formation of siderite and in all probability part of the iron in the primary segregation was precipitated as siderite and either replaced the rocks or filled fissures just as the pyrite did. In the Wharton mine, southeast of Hellertown, the carbonate ore was less abundant in the lowest workings than it was a short distance above them, which might mean that it did not extend into the region of unaltered primary mineral deposition and thus point to its secondary character. At present it is well to consider the carbonate ores as in part primary and in part secondary and not to attempt to say which class is the most important.

Secondary concentration of the iron ores.—The present workable iron deposits are the products of alteration of the original segregations of pyrite by descending waters carrying oxygen and carbon dioxide in solution. Some of the sulphide was changed directly to limonite, forming a spongy ore characteristic of gossan deposits; other portions were altered to limonite that was taken into solution and metasomatically replaced part of the associated quartzite or was precipitated in open spaces as stalactites of limonite; and still other portions were converted into siderite and precipitated as bombshell ore or compact rounded concretions. Numerous specimens il-

[4]Chance, H. M., Am. Inst. Min. Eng., Trans. vol. 39, pp. 522-539, 1909.

lustrating each of these processes have been found in the vicinity of the abandoned iron mines along the slope of South Mountain between Emaus and Mountville.

The following chemical reactions illustrate some of the probable changes which took place.

$$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4$$
$$6FeSO_4 + 3O + 3H_2O = 2Fe_2(SO_4)_3 + 2Fe(OH)_3$$
$$2H_2O + FeSO_4 + CaCO_3 = FeCO_3 + CaSO_4.2H_2O$$
$$FeCO_3 + H_2O + CO_2 = Fe(HCO_3)_2$$
$$Fe(HCO_3)_2 + CaCO_3 = FeCO_3 + Ca(HCO_3)_2$$
$$2Fe(HCO_3)_2 + O + H_2O = Fe(OH)_3 + 2CO_2$$

In most places the descending waters probably deposited the iron minerals in more concentrated bodies than had been done in the primary mineralization, yet this may not have been true everywhere. In some places where large deposits of pyrite had existed, the mineral waters that resulted from the oxidization and solution of the pyrite were probably dispersed and lost.

As siderite is not stable in the presence of highly oxygenated surface waters it has practically all been changed to limonite near the surface but still persists a short distance below the groundwater level. In many of the mines siderite nodules partly altered to limonite can be found.

The pyrolusite found with the limonite has had a similar origin. It probably existed in the pyrite and on oxidation was changed to its present form. Part of the manganese has been segregated to form masses of practically pure manganese oxide, but the bulk of it is intimately mixed with the limonite.

In places large rounded masses or small botryoidal segregations of secondary chalcedony are abundant. These masses occur in the clay and may have been formed by ascending waters at the time the pyrite was concentrated or more recently by descending waters. Lack of information regarding their distribution in depth prevents any positive conclusion.

In some of the mines in the limestones there is every indication that the limonite deposits are the result of precipitation from decending waters alone, no pyrite ever having been present in the immediate locality, as the limestone floor gives no indication of the presence of deep fissures through which ascending waters might have brought pyrite. In such places the deposition of the limonite has been produced by percolating waters which dissolved the disseminated iron minerals that were present in the overlying strata and carried them as sulphates or bicarbonates until they were checked by impervious shaly strata in their downward movement

and became stagnant and then gradually precipitated the iron in the form of limonite or carbonate, probably by coming into contact with other surface waters that carried oxygen in solution. Such an origin is generally believed to account for most of the limonite deposits that are so widespread in the Appalachian region. According to this theory all limonite deposits would form only close to the surface, and as they could scarcely be expected to form rapidly, the regions where they are found must have been subject to very little erosion for a long period or else they would have been removed by erosion.

During the period of stability in Tertiary time when the Swarthmore peneplain, so well represented in the limestone valleys, was developed, conditions were favorable for the formation of ore bodies in this manner, and no doubt many of the brown iron ore deposits of the valley-ore type were formed at that time. Similar ore bodies were probably formed during the periods of Harrisburg and Schooley peneplanation, but these deposits have been largely if not entirely removed by subsequent erosion, which has destroyed all portions of these peneplains in the limestone valleys.

Prime,[5] in his discussion of the iron ores of the region, suggested a secondary origin of a different character for some of the deposits then being worked. He says:

> The whole appearance of the mine is that of a secondary deposit and seems to point to the ore not being in place. All through the yellow clay there are fragments of rock—limestone, damourite slate, and quartzite. The two former are angular, the latter more rounded. The conclusion arrived at by the writer is that the entire deposit has been formed during the Drift period; the ore, rock and clay having been pushed down from deposits to the north or northwest and deposited here in a depression of the limestone rock.

There is no doubt that much of the limonite picked up in the fields owes its present position to transportation by the ice during the glacial epoch but it is extremely doubtful whether any workable deposits have been formed in this manner, as suggested in the passage quoted.

The clay that is associated with the limonite ore represents the residual materials left by the decomposition of aluminous and siliceous strata. These clays were formed at the same time that the secondary concentration of the ore took place. In places shaly laminae or shale partings are interbedded with the limestones and sandstones, and these strata would yield much clay. Prime believed that the black clays had been formed from some of the overlying Ordovican black slates, which he called Utica slates. In some of the descriptions of individual mines quoted from his report (p. 53), statements of this kind are made. The irregular distribution of

[5]Prime, Frederick, Jr., Pennsylvania Second Geol. Survey, Rept. D3, vol. 1, p. 201, 1883.

the black clay and its occurrence in some places in detached masses beneath clays unquestionably formed from strata interbedded with the limestones and sandstones preclude such an origin. It must be admitted, however, that the formation of the different kinds of clay—red, white, drab, blue, and black—found in the mines of the region, presents many unsolved problems. Information is lacking in regard to the original character of the beds which gave rise to these varieties of clays. At the surface these strata have been thoroughly decomposed, and there are no deep excavations to furnish the desired data.

The depth to which the clay and the brown ores extend, nearly 200 feet in several places, indicates free underground drainage. Where the rocks have been decomposed to so great depths the structural features, such as the fracture zones previously mentioned, openings between bedding surfaces caused by the uptilting of the strata, and the alteration of limestones and shales or sandstones and shales, favored the collection of the surface waters into channels and produced the localization of weathering described. The depth to which the limonite and the clays extend implies that outlets for subterranean drainage existed at equivalent or lower elevations.

As the decomposition and removal by solution of portions of the strata proceeded the ground gradually settled downward, producing sink holes, which would still further increase the volume of percolating water through the collection of more of the rain water, which formerly reached the surface streams. When the ice sheet advanced over the limestone valleys these depressed areas were largely obliterated by the deposition of glacial débris, which is generally thicker over the iron-ore deposits than elsewhere.

The settling of the clay owing to the shrinkage of the rocks also resulted in the breaking of the particles of iron ore, producing the "wash ore" described elsewhere in this report.

Method of Working.

Most of the limonite mines of the limestone regions have been worked by open cuts, especially in the early stages, and many of the mines of the Cambrian quartzites were also worked in that way. The great quantity of clay and the few ledges of hard rocks associated with the ore at first favored open-cut work, but as the excavations increased in depth the loose materials tended to slide into the pits after heavy rains, and shaft mining replaced the former method. In numerous places shafts have been sunk in or near old pits. Where the mines were located on steep slopes, as were many of those in the Cambrian quartzite, the deep cover of hillside wash rendered shaft mining necessary from the beginning.

In open-cut mining the main body of ore, which occurred in a more or less veinlike form, was followed, but mining was not restricted to these bodies. Throughout the mass of clay considerable wash and lump ore would be found, sufficient to justify practically everything being taken out and run through the washers for a considerable distance on either side of the body of concentrated ore. In this way, in some places, several acres were worked over. When a pit was first opened horses and carts were used to haul the ore to the washer, but as the mine became deeper inclined tracks were laid, up which the ore was hauled in small cars. In the open-cut mines of the limestone regions the limestone floor was very irregular. The rock came within 25 feet of the surface in many places, but elsewhere it was not reached at the greatest depths. In general the ore is concentrated to a greater degree where the decomposition of the rocks has proceeded to a great depth, as the ground waters which followed the most open passageways accomplished both the decomposition of the rocks and the segregation of the ore.

In shaft mining the veinlike ore bodies were followed in drifts run at different levels and stopes were raised to the levels above. Most of these bodies of ore are approximately parallel to the strike of the inclosing rocks, especially in the Cambrian quartzites, where certain layers were more easily replaced than others. When the ore that was being followed became lean or disappeared crosscuts would be made to either side or the direction of the drift changed in a haphazard manner. In the operation of some mines it was assumed that more ore would be found by drifting in a certain direction, and if this surmise proved incorrect efforts would be made to find ore in another direction. Pockets of good ore were thus likely to be located after several attempts, and at the same time a few lumps and small fragments of ore would be found while driving the exploratory drifts.

The loose clay through which the shafts and drifts are driven may be said with little exaggeration to be in constant motion from the time mining starts until all the openings are filled by caving after mining has ceased. Shafts must be abandoned on account of squeezing, which pushes them out of plumb, and drifts tend to close through the pressure, which at times becomes so great that large timbers are broken or shoved out of position. In most mines it was necessary to timber both shafts and drifts very carefully, and the close timbering prohibited any examination of the occurrence of the ore except at the working face.

In most mines there were no ore chutes or loading pockets, as the activity of the mines was of too short duration to warrant their construction and also the great amount of clay present would have prevented the ore from running through them. In some mines the ore

was loaded in buckets that were placed in a small car, which was then pushed to the bottom of the shaft and hoisted. In other mines small cars were used without the buckets.

The quantity of water encountered was a serious obstacle to the mining in almost every mine that exceeded 50 to 75 feet in depth. Cornish pumps were used in almost all the mines, and the water was employed in washing the ore.

The mining equipment was never elaborate, because of the character of occurrence of the ore, and the output of any particular mine was consequently small. It is doubtful whether the output of any of the mines averaged more than 35 tons a day, and in most of them the average output was less than half that quantity.

Preparation for Market.

The large amount of clay invariably associated with the limonite ore necessitates washing most of the ore before it can be shipped to the furnaces. In some mines masses of fairly pure ore were obtained that were practically free from adhering clay, and these were ready for shipment as mined, but this material was exceptional.

In the washing process several modifications of the common log washer were used. In its simplest form this device is merely a log or shaft to which are attached, in a spiral arrangement, iron plates that project a few inches. This log, which can be rotated, is set at an angle and surrounded by a trough, into which the mixture of ore and clay is dumped. Above the trough runs a water pipe or small trough with numerous perforations through which the water passes to mix with the clay and ore. The ore and the associated clay are dumped into the lower part of the trough, and the log is rotated to carry the large particles upward to the end of the trough, where they fall on a platform, while the water carries the clay in suspension to the lower part, where it flows into a line of wooden troughs, usually supported by trestles, that convey it to a settling pond.

If the clay adheres very firmly to the ore it may become necessary to reverse some of the teeth or plates in the log in order to retard the passage of the ore and give them more opportunity to loosen the clay.

In the washing process pieces of chert or other rocks remain with the ore and must be picked out by hand and many small fragments of ore are washed away by the water.

Most of the mines yielded enough water for washing the ore, but at times some of them had to obtain additional water from wells or

near-by streams. In some places the comparatively clear water from the settling ponds was drawn off into another basin and again pumped to the washers.

The daily average of ore handled by a single washer was never large but ranged from 15 to 35 tons.

Economic Considerations.

If a region where iron mining was once one of the principal industries gradually undergoes a change by which all the mines are closed and yet the iron-manufacturing industry still continues, the natural conclusion would be that the iron ore deposits had been exhausted. In the Allentown quadrangle, however, where 133 limonite mines are known to have been worked and at present none are in operation, other causes have contributed to the existing situation. Many of the mines were worked out or abandoned because the ore was too lean, but many of them were closed for other reasons, and it is not improbable that as much ore still remains in the ground as has ever been mined. Many of the mines when closed had as much ore in sight as at any preceding period, and undoubtedly there are numerous deposits that were never worked. When the fields are freshly plowed many promising places for prospecting can be distinguished by the brown color of the soil and the fragments of float ore, which favor the conclusion that many ore deposits have never been developed.

In the early days many of the iron companies that operated furnaces acquired ore properties which they either worked or leased under the arrangement that all the ore would be sold to the furnaces at current prices. The royalties paid ranged from 20 to 50 cents a ton. In addition many independent companies acquired ore properties and engaged in iron mining and always found a ready market for their ores. In recent years, however, a great change in the iron industry has resulted in the closing of many of the small independent furnaces and a concentration of the iron business in a few large companies. The disposal of pig iron made by the small independent furnaces has become increasingly difficult, and many of them have had to close. The larger companies have found so many objections to the local brown iron ores that for many years the mining of them has continued to decline, although a few mines in neighboring regions are still in operation.

Perhaps the chief objection to the local brown iron ores is the variability of the supply. In winter the severe weather prevented open-cut mines from operating, and the condition of the roads at

times interfered with the delivery of the ore. The output of a few of the largest mines is given elsewhere (p. 62) to show the variability in the supply. No concern that uses a large quantity of ore wishes to contract for a supply that is so uncertain.

The variation in composition is also a drawback to the utilization of the local limonite ores. As shown elsewhere, both the iron content and the amounts of silica and phosphorus were extremely variable and hence objectionable. The ore averages too high in phosphorus for Bessemer ore, and none of it is high in iron. The average limonite ores of the district contain only a little more than 40 per cent of iron. Under such conditions it was inevitable that high-grade iron ores that are low in phosphorus, such as the Lake Superior ores, should replace the local ores when improved transportation facilities permitted competition.

The mine operators also encountered difficulties in the profitable operation of their properties because of the increased cost of labor and the additional cost of pumping the water as the mines became deeper. The result was that many firms hesitated to open new mines when it became necessary to abandon their old ones and decided to disband. Conditions are not now sufficiently favorable to attract new capital to the iron-mining industry.

The future of the mining of brown iron ore in this region is problematic, yet there is reason to believe that at some time it will be actively resumed, although this will be brought about only by the exhaustion of richer ore deposits of other regions which now supply the local demand. Thus the mining of brown iron ore will not be an important industry in this region for many years, as the Lake Superior, New York, and foreign ores will long continue to compete with the local ores. The local operations are necessarily small on account of the manner of occurrence of the ore and so can not compete with operations in these regions, where mining can be done on a very extensive scale.

Limonite Mines of the Cambrian and Ordovician Limestones ("Valley Ores").

Many of the descriptions that follow are copied from reports of Frederick Prime,[6] who had opportunity to study some of the mines in operation which have now long been abandoned. The numbers refer to the map locations. The quoted descriptions are inclosed in quotation marks; notes not so indicated are added by the present writer.

[6] Pennsylvania Second Geol. Survey, Repts. DD, 1872, and D3, vol. 1, 1883.

2. Abraham George's mine.—"Leased by the Saucon Iron Co. This mine is lying idle and is full of water. The sides are too much washed to see anything of the nature of the deposit, further than it occurred associated with a black damourite slate or shale, which is probably Utica shale, judging lithologically from the character and position of identically the same shale in Lehigh county near Breinigsville. This shale is full of pyrites, which take fire on exposure, owing to their oxidation, and set fire to the carbon in the slate".[7]

The excavation is approximately 200 feet long E and W, 90 feet wide, and 40 feet deep. There seems to have been some underground workings. No rock is exposed in the sides of the pit, but limestone appears in a small pit south of the large openings. Water from this pit has been pumped to the mill of the Bath portland cement plant.

3. William Chapman's mine.—"When visited, about 3 to 10 feet of stripping had been removed and there the pit presented a promising appearance. The mine had not been developed sufficiently to say whether there was a large body of ore or not. A shaft had been sunk to the depth of 65 feet, which was said to be all the way down in solid ore, but this statement is probably incorrect. The well for water had been sunk down 125 feet. At a depth of 30 feet limestone was struck and going through this, ore was said to be found underneath it (?). The ore is mostly of the bombshell variety, and inside of the hollow bombs white (damourite) clay frequently occurs, but at the depth to which the mine had been excavated no white clay was to be seen; an exception in this respect to the usual occurrence".[8]

4. Aaron Lerch's mine.—"Leased by the Crane Iron Co. In this mine black clay (decomposed Utica shale) is found in which there is a deposit of red ore (so-called "red rock ore"); the clay occurs beneath a small deposit of white clay, over which lies brown hematite in which white and gray clay occurs sparingly. The red ore also occurs in the bottom of the mine underneath the black clay. The sides of the mine were very much washed and it was difficult to see much of the nature of the deposit".[9]

This is one of the largest open pits of the region. It is very irregular in shape and about 1,600 feet in width at the widest part. At one place limestone is exposed in the bottom of the pit.

A typical analysis of this ore by James Gayley in 1878 gave the following results:

Fe	43.59
Mn	1.34
Al_2O_3	2.36
Ca	2.15
Mg	.62
SiO_2	23.51
P	.381
S	trace
Water	7.69

7. Henry Goetz's mine.—"Leased by the Coleraine Iron Co. This is one of the oldest mines in the county and was finally abandoned in 1877 as being worked out. When visited in 1875-76 the bottom was full of water and ore was being taken out near the top at the northern end, where a little red ore was left. As seen close to the bottom the ore occurs in and above a black clay (Utica shale), which containing a good deal of pyrites—perhaps marcasite—oxidizes rapidly on exposure and the surface is covered with an efflorescence of sulphate of iron. A little reddish sandstone was seen on the dump, but could not be found on the sides of the mines, although carefully searched after. Over the black clay there occurred in spots heavy bodies of white clay, in some places containing ore, in others none whatever. It is probable that the Utica shale seen here is a remnant of the period when the whole of the limestone was covered by the slates (No. III) and that being caught in a synclinal of limestone it was preserved from erosion at the time when the great body of slates was washed away. Many thousands of tons of ore have been taken from this excavation and it is a curious coincidence that the mine should have been exhausted just about the time that its aged owner died".[10]

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[7]Idem, D3, pp. 197-198.
[8]Idem, p. 198.
[9]Idem, p. 198.
[10]Iden, pp. 199-200.

The excavation covers several acres and is one of the largest mines of the quadrangle. The pit is now about 75 feet in depth. The ore from this mine averaged 43.59 per cent iron and 23.30 per cent silica.

This mine was one of the largest in the quadrangle and one of the few mines from which statistics of production can be obtained. Practically all the ore went to the Crane Iron Co. at Catasauqua, from whose books the statistics were obtained. The annual production ranged from 250 tons in 1870 to 4,941 tons in 1845, and the total production from 1841 to 1888 was 98,486 tons.

8. *Gernet's mine.*—"This has not been worked for some time and its sides are much washed. At one point in the mine there is a dark liver-brown clay (Utica shale) containing glistening particles of pyrites. On the dump there is a little white clay." [11]

9. *Milton H. Kohler's mine.*—"On the north side of this excavation there is a heavy deposit of white clay coming to the surface; the pit being chiefly worked at the west end, where there is a good show of ore, a good deal of which is of the bombshell variety; this occurs embedded in seams of white clay. Close to it there are limestone boulders, formed by the dissolution of limestone, containing thin beds of hydromica slate. The white clay seems in part at least to have been formed by the solution of limestone containing damourite." [12]

11. *Simon Ritter's mine.*—"This is not being worked at present. On the south side of the mine occurs limestone, much waterworn, dipping S. 38° E., 34°, this being the only certain dip, although there are several points in the bottom of the mine where the limestone appears. Close to this dip there is a little white clay but not in any abundance. It is possible that the ore has here been washed into a depression of the limestone and was not originally deposited there; in which case ore need only be looked for in the sides and not at any great depth. One very important fact militates against this view, and that is that in an abandoned mine on the opposite side of the road, now filled up, there occurs black clay (Utica shale) containing great lumps of iron pyrites, which turn on exposure to sulphate of iron and effloresce. This would tend very strongly to prove that the ore of both the mines is in place, and the limestone is the underlying Trenton limestone (No. II), in which no further search for ore need be made. There also occur large flints associated with the iron ore." [13]

12. *William Ritter's mine.*—"This is not being worked, and the machinery has been removed. This deposit is apparently confined to the surface and is not in place. It looks as if the ore had been washed in during the Drift period, and it is associated with pieces of flint and boulders of limestone. The sides are much washed." [14]

16. *Solomon Hummel's mine.*—"At this place only the stack for the washer has been erected and 5 or 6 shafts sunk within a diameter of 50 feet. There is a great deal of large lump ore at the mouth of each shaft, so that the locality presents a promising appearance." [15]

17. *Samuel Schortz's mine.*—"This has not been worked for some time, so that as usual in such cases the sides are much washed. In the most eastern part of the pit there is a little white clay on the north side, containing fragments of damourite slate, but this is too little exposed to justify any conclusions. In the most northern part of the mine white clay again appears, which is apparently stratified; and below this, yellow clay containing angular flints, which also apparently occur in the white clay; but the white clay here contains a good deal of yellow clay—also plastic—disseminated through it, so that when moistened the whole presents a yellow appearance. As this part of the pit is inaccessible it could not be viewed very closely. At the east and north end there is an abundance of ore distributed through the yellow clay." [16]

18. *J. Beck's mine.*—"Leased by F. Jobst. This has not been worked since 1873. But little could been seen on this account, but the whole deposit looked as if it was a secondary one and not in place. A good deal of ore has been taken out, however, which is not often the case with deposits of a secondary character." [17]

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[11] Idem, p. 200.
[12] Idem, p. 200.
[13] Idem, pp. 198-199.
[14] Idem, p. 200.
[15] Idem, p. 200.
[16] Idem, pp. 200-201.
[17] Idem, p. 201.
[18] Idem, p. 201.

19. William G. Beck's mine.—"This has not been worked since 1873. The west end is inaccessible on account of water. The ore apparently occurs stratified in white clay, with white clay over it. At this mine the white clay comes within 6 inches of the surface and is about 15 to 18 feet thick, and there are alternate layers of ore and clay about 12 feet thick. From the small exposure it was impossible to arrive at any conclusion as to whether the ore was in place or was a secondary deposit." [18]

20. John Lawall's mine.—"Leased by the Crane Iron Co. This has not been worked since 1874. In the middle of the north side a single spot of white clay is visible. In places small fragments of slaty limestone containing damourite and small bowlders can be seen. It looks like a secondary deposit. The ore was found to be so unsatisfactory that work was stopped at the mine in the fall of 1878."

Joseph Hunt, assistant superintendent of the Crane Iron Co., furnished the following partial analysis made by Mr. James Gayley, the company's chemist:

Silica	24.62
Lime	1.74
Manganous oxide	2.92
Metallic iron	42.84
Phosphorus	0.431

23. Gernst & Heller's mine.—"Has not been worked since 1874. On the washed sides are small pieces of fresh and partly decomposed damourite slate and iron. The former is of a gray color. There are numerous pieces of quartzite both round and angular from the size of a large watermelon to very small pieces. The ore on the dump is much of it very light, and the large lumps in some cases contain brecciated damourite slate, as if this had been cemented together by the hydrated ferric oxide." [19]

25. Dr. B. C. Walter's mine.—"The main excavation has not been worked since 1874 and was much washed. In 1876, when visited, new shafts were being sunk. These had in some cases struck white clay, with limestone below it, but very little ore being met with. The outlook when visited was not very promising." [20]

28. Thomas Richard, Jr. mine.—"This consists of a tract of several acres, covered with ore pits and surface excavations. The ore apparently only occurs in surface soil, and does not extend to any depth." [21]

33. Henry Hoch's mine.—The first ore hauled to the furnace of the Crane Iron Co. at Catasauqua came from this mine. It was worked at intervals from 1840 to 1908. It is an open pit mine about 300 feet long, 200 feet wide, and 75 feet deep. The ore was unusually red in color, owing to the presence of much goethite, and averaged about 43 per cent iron. An anaylsis made October 30, 1890, by the Crane Iron Co. of high-grade ore is as follows:

Fe	48.308
P	.340
S	trace
SiO_2	11.850
Al_2O_3	2.927
MgO	trace

The ore was regularly distributed through the clay in the form of large masses, which could be picked from the clay by hand, and also as small pieces called "wash ore", which were obtained by passing through a long washer.

Fairly complete statistics of production except for the last few years the mine was worked, have been obtained from the books of the Crane Iron Co., which used practically all the ore. The annual production according to these statistics, ranged from 24 tons in 1860 to 4,073 tons in 1840. The total production from 1840 to 1898 was 29,129 tons.

42. Samuel Lerch's mine.—"This was formerly leased by the Coleraine Iron Co., who took out about 50 tons of ore and then abandoned it. The excavation is now almost filled up, and is overgrown with underbrush. The ore was taken out of

[19] Idem, p. 202.
[20] Idem, p. 203.
[21] Idem, p. 203.

drift and surface soil. There seems to be a good deal of ore in the surface of the field: but it is very questionable whether it would pay to wash the surface soil for it."[22]

47. Daniel C. Kline's mine.—An old open-cut iron mine. The only evidence that it was in limestone is the presence of fragments of retten limestone in the material washed from the ore.

"The limonite occurs in decomposed hydromica slate. The laminations or dip of the slate is S. 25°—30°. The dip is variable and ranges from S. 10° W. to 10° E."[23]

48. Schneider's mine.—"The ore is associated with decomposed slate and clay. A number of large openings have been made."[24]

54. Greene mine.—A very large excavation. The mine was owned and operated by the Saucon Iron Co. The ore contained some zinc. In the lowest workings considerable pyrite was found. The mine was closed when the Friedensville zinc mine pumps were stopped, as the water was too great to permit profitable mining, although a large body of ore was in sight at the time.

68. Wint mine.—"The limonite occurs in lenticular bodies in decomposed sandy hydromica slate. Thin beds of limestone have been found in the mine. The ore deposit is irregular. The dips observed are W. 10°—15° and S. 45° W. 15°. The mine appears to be located near the base of the slates. The ore is very siliceous, owing to the large amount of sand which occurs in the slate."[25]

71. Bahl mine.—This was one of the largest limonite mines of the Saucon valley. The ore, which averaged about 42 per cent iron, occurred in rather definite veins about 10 feet wide. In addition much ore of the bombshell variety was disseminated throughout the clay. A large amount of carbonate ore was mined. The mine was worked entirely by open cut. The excavation was about 100 feet in depth and in spring much clay from the sides would slide into the pit.

It is estimated that 500,000 tons were taken out of this mine by the Thomas Iron Co., the Bethlehem Iron Co., and the Coleraine Iron Co.

A paint company, located nearby, used part of the mud-dam material for paint for many years. The Bingen Brick Co. at the present time is using the material in the manufacture of brick.

Limonite Mines of the Cambrian Quartzite ("Mountain Ores").

76.—A long abandoned pit in which only clay is exposed. Small pieces of Cambrian quartzites near the pit indicate that the ore was in the quartzites.

77. Thomas Richard's mine.—"In the open cut this is only worked in the east end, where there is a good body of ore, which seems to be cut off further east by white clay. The ore occurs apparently instratified in the white clay. To the west a shaft has been sunk down 107 feet to the ore. In going down a body of damourite slate and clay was struck, which at a greater depth turns into a blue clay. Underneath the ore there is said to be black dirt, but none could be seen. The bed is said to be 27 to 40 feet thick, but this had to be taken on hearsay evidence, as the mine was so closely timbered that it could not be measured. East of this another opening has been made in the roadside, but so recently that only stripping was being taken out and washed."[26]

This mine, which was worked for about 25 years, was closed about 1900.

78-80.—This group comprises a line of old workings that seems to indicate a persistent ore body that was rather closely confined to a definite horizon in the Cambrian quartzite. As the rocks dip steeply to the north and strike parallel to the hill the old workings appear as a wide and deep trench along the side of the hill. The ore is said to have been found in decomposed slate and clay. The mud dam deposits from these mines are dug and used for building sand.

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[22] Idem, p. 196.
[23] Idem, p. 235.
[24] Idem, p. 230.
[25] Idem, p. 234.
[26] Idem, p. 196.

81.—Extensive working are indicated by the size and depth of the old pit. The Crane Iron Co. worked the mine. One shaft was 67 feet deep.

82.—An old shaft mine, worked by Laubach & Riegel.

83.—This shaft mine was worked for 13 years by Dr. Madden. The workings have now caved, and the size of the pits formed shows that a large amount of ore was mined.

84.—*Wassergass iron mine.*—The mine is unique in that about 15 feet of coarse pebbly sandstone, which dips to the north at an average angle of 75°, forms a distinct footwall. The ore was formed by the replacement of certain layers of the quartzite and scarcely affected the adjoining strata. The ore was mined on either side of the road.

85. Daniel Schwartz's mine.—"There are about 15 feet of surface soil above the clay and ore. In the west end there is a mass of flint or quartzite colored black by iron and intermingled with ore, which is all broken up, over which lies bedded gray flint, and beneath the ore white clay. In the middle and east end the show of ore is better. The pit is worked at these points and contains ore as far down as it is worked. Where seen clay occurs intermingled with and apparently underlies the ore. In the east end the ore apparently dips southeast. The middle of the mine is leaner than the east end. The mine has been worked many years and a large amount of ore taken out of it, but present appearances would indicate that it is not far from being exhausted." [27]

Prime gives the following anaylsis of the ore from this mine by Mr. D. McCreath:

Iron	34.000
Manganese	.115
Sulphur	.020
Phosphorus	.676
Insoluble residue	37.695

This mine shows more clearly than any other mine in the region the way in which the ore has been formed by replacement of the yellow chert. Along the strike of the beds certain portions have been almost entirely changed to limonite, but other portions consist of almost pure chert with only enough iron present to color it yellow.

86. Trexler & Kline's mine.—"This pit is now abandoned and apparently exhausted, having been worked to the underlying Potsdam sandstone. White clay has immediately overlaid the sandstone, since remains of it can be seen in the crevices on the upper surface of the latter. It may be possible, although not very probable, that more ore will be found on descending deeper. At this pit, also, white clay underlies the ore." [28]

According to Prime, samples of the ore were collected and sent for analysis to Mr. David McCreath, who found:

Iron	36.500
Manganese	1.325
Sulphur	0.107
Phosphorus	0.547
Insoluble residue	31.215

87. Jessie Kline's mine.—"In this pit, now abandoned, the ore and clay can be seen conformable with the underlying Potsdam sandstone, the latter containing *Scolithus*. There are places where it looks almost as if the sandstone was running into limonite." [29]

[27] Pennsylyvania Second Geol. Survey Rept. DD, p. 26, 1872.
[28] Idem, p. 27.
[29] Idem, p. 27.

Prime gives the following anaylsis:

Iron	47.200
Manganese	2.709
Sulphur	0.039
Phosphorus	0.075
Insoluble residue	14.980

Near this mine and adjoining mines it is possible to find many fragments of rock that grade into ore in such a manner as to leave no doubt that Prime's surmise is correct.

90. Henry Kline's mine.—"Leased by Jobst and ———. There are two openings here. At the smaller one, which lies just below the gneiss of the South Mountain there was a small nest of black oxide of manganese, 8 inches thick, which has since been worked out. The ore lay directly against the Potsdam sandstone. There is white clay in this pit, which is very gritty and is in part decomposed Potsdam sandstone. The gneiss, under the sandstone, is granitic, very quartzose and contains a little martite or red hematite. In the larger pit the mine had been only reworked a single day when it was visited. There was not much ore in sight, the little that was seen lying in white and yellow clay. At the east end there is Potsdam sandstone in the bottom, apparently in place, with an undeterminable dip. The ore is here very close to the sandstone and must be sought for in depth, if present at all."[30]

According to Prime, samples of it were analyzed by Mr. David McCreath, with the following result:

Iron	30.100
Manganese	.489
Sulphur	.062
Phosphorus	.299
Insoluble residue	43.035

91. Henry Kline's mine.—"At this pit, which is abandoned, nothing can be seen. A shaft has been sunk through the clay 30 or 40 feet, but from the character of the material on the dump little or no ore has been found." [31]

92, 93 & 94. Martin Kemmerer's mine.—"The first pit is now abandoned and full of water. Shafts have been sunk around it and filled up. On the dumps can be seen a little pipe ore and white clay. [Nos. 93 and 94] are both abandoned and grass grown. The ore has either been exhausted or deeper workable deposits of ore have been touched by the shafts." [32]

95, 96. Keck & Ritter's mine.—"Leased by Emaus Iron Co. [No. 95] is abandoned and no ore can be seen on the banks. In [No. 96] the ore is sporadically distributed in yellow clay. Not far from the bottom there is a bed of white clay about 6 inches thick. It may be that the ore in the bottom is in place, but it does not present that appearance. There is a great deal of flint associated with the ore. The mine does not present a very promising appearance."[33]

Prime says that the ore which was analyzed by Mr. A. S. McCreath, yielded:

Iron	39.250
Manganese	5.512
Sulphur	.029
Phosphorus	.149
Insoluble residue	21.880

[30]Idem, 27-28.
[31]Idem, p. 28.
[32]Idem, p. 28.
[33]Idem, pp. 28-29.

97, 98, 99. G. Kline's mine.—No. 97 "is abandoned; there is a great deal of lump ore on the dump. The sides are caved in, but at one point the Potsdam sandstone was seen decomposed to a beautiful variegated sand. The ore was taken from clay and damourite slate directly overlying the sandstone. Of the two pits at [No. 98] the southerly one shows nothing. A drift has been driven in close to it in which nothing can be distinguished and which does not penetrate very far. On the other pit and at [No. 99] nothing can be seen, but a number of shafts have been sunk and there is quite a good deal of lump ore on the dumps, apparently enough to pay for working when the present depressed period in the iron industry improves." [34]

102, 103. Hottenstein's mine.—"Potsdam sandstone underlies and overhangs pit [No. 102] and in this there are boulders of sandstone. At [No. 103], which is also not worked, there is sandstone in the west end, probably boulders. But nothing could be seen relating to the nature and position of the ore." [35]

104. Milton Apple's mine.—"At this pit there are boulders of Potsdam sandstone and debris from which ore has been taken. A shaft 20 feet deep shows the same in the bottom. This pit was not being worked when visited." [36]

105. Kipping & Holsbach's mine.—"This pit was not being worked. Only yellow clay and drift could be seen, there being no ore in sight. At one point a drift has been run in, which is now fallen shut." [37]

106, 107, 108, 109. Conrad Scam's mine.—"At [No. 107] can be seen first surface drift, then white clay. next ore and finally white clay again to the top of the water in the bottom of the pit; the appearance of the ore is good. [No. 106] was being worked for the Allentown Iron Co.; the ore occurs in white and yellow clay. [No. 108]. which is not being worked, shows ore on the south side in white clay. [No. 109] was not being worked. A sample was taken from the opening [No. 105], it being all wash ore, and an analysis of all the constituents it contained made by Mr. D. McCreath as a type of the ores of Lehigh County." [38]

McCreath's analysis, quoted by Prime, is as follows:

Ferric oxide	69.714
Manganic oxide	1.292
Alumina	2.388
Lime	.300
Magnesia	.317
Sulphuric acid	.035
Phosphoric acid	.448
Water	11.340
Insoluble residue	13.915
Iron	48.800
Manganese	.900
Sulphur	.014
Phosphorus	.196
	99.749

110, 111, 112. Whitman's mine.—"Leased by Emaus Iron Co. [No. 110] is being worked; the ore occurs in white and yellow clay, there being but little ore in sight when the mine was visited. [Nos. 111 and 112] are numerous small openings not worked and the sides too much washed to see anything."

113. This excavation seems to have been an iron mine. Numerous masses of sandstones and chalcedonic quartzites and some limonite were seen. The limonite shows clearly that it was formed by replacement of the quartzite.

116. "Red" mine.—Mining at this locality was carried on over an extensive area, the refuse being thrown in the old workings. The abundance of quartzite fragments in the clay seems to prove that the ore was of the "mountain" variety.

118. Newmeyer's mine.—"The limonite is deposited in irregular lenticular bodies. The dip appears to be undulating to the eastward 5° to 15°. A large excavation has been made to a depth of about 40 feet at the deepest point." [39]

[34] Idem, p. 29.
[35] Idem, p. 29.
[36] Idem, p. 29.
[37] Idem, p. 29.
[38] Idem, pp. 29-30.
[39] Pennsylvania Second Geol. Survey Rept. D3, vol. 1, p. 225, 1883.

121. Erdman & Cooper's sand pit (mine.)—"Located on the south side of the Center Valley-Saucon Valley Post Office pike 1 mile west by north of Center Valley. The limonite is associated with decomposed sandstone and hydromica slate. A large amount of siliceous matter occurs in the ore. Decomposed feldspar is found on the surface. The pit is close to the edge of the feldspathic rocks."[40]

122. Sill & Jordan's mine.—"There are several small openings 20 to 30 feet deep and 10 to 20 feet wide. The limonite occurs in clay and sand; no slate is visible."[41]

123. Hiram Eisenhart's mine.—The shaft is about 35 feet deep. A small amount of ore has been taken out.

124. Bachman mine.—The Bachman mine was opened in 1887 and worked for about five years. About 15,000 tons of good ore was taken out. The ore became lean, and the mine was abandoned. The great masses of yellow chert in the east part of the pit show conclusively that the ore was formed by replacement of Cambrian quartzite. Some of the ore contains considerable wavellite and cacoxenite, but so far as known no objection was ever raised on account of the phosphorus present in the ore.

125. Kauffman mine.—The Kauffman mine was similar to the Bachman mine. It was worked by the Crane Iron Co.

127. Blank mine.—The Blank mine was operated intermittently for about five years and was closed in 1888. The ore was of good quality and was high in manganese. The vein was fairly thick, but the mine failed to pay because of poor equipment.

128. Wharton mine.—The Wharton mine, located about 2 miles east of Hellertown, was first opened by George Wharton in 1852, who worked it as an open pit for several years. The mine was abandoned and no work done until 1872, when it passed into the possession of the Saucon Iron Co. It was then reopened and worked for about 12 years and then again abandoned, as it could not be profitably worked longer by the open-cut method. In 1884 the Thomas Iron Co. purchased the property and at once began to sink a shaft. It was worked more or less continually until 1910, when it was finally abandoned, because the old shaft had been forced out of plumb by the pressure of the clay that slipped down the slope and it was not thought advisable to bear the expense of a new shaft.

The ore was found in yellow, white, and red clays segregated in veinlike bodies 5 to 10 feet in width which in general headed eastward, parallel to the direction of the valley. At the 150-foot level one of these ore bodies which had a high angle of dip toward the mountain was traced for about 1,100 feet. The ore also was found in large and small masses irregularly disseminated throughout the clay. Great masses of chert, some of which were 4 feet in diameter, were rather common in association with the clay and ore. The accompanying map of the mine workings shows the relation and direction of the main ore bodies.

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[40]Idem, p. 232.
[41]Idem, p. 233.

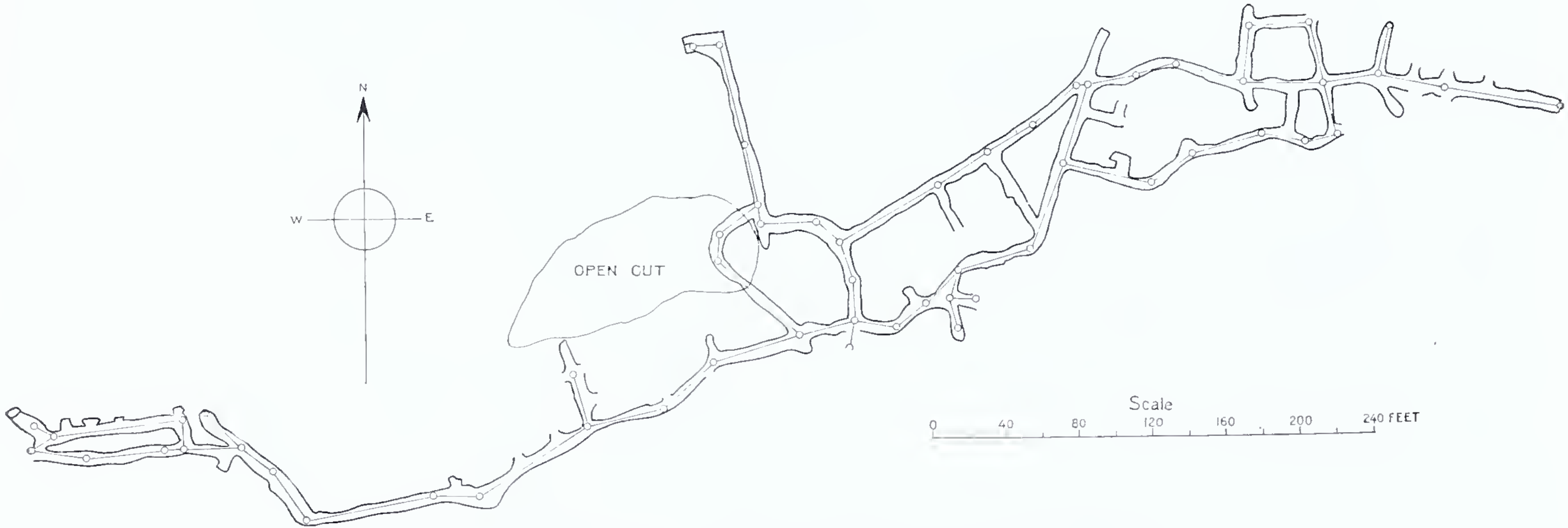

Figure 2. Map of Wharton Iron mine, 2 miles east of Hellertown, Pa.

The ore was high in manganese and was consequently always in demand. A large number of analyses shows that the ore contained an average of about 43 per cent iron, 19 per cent silica, 4.21 per cent alumina, 2.18 per cent manganese, 0.377 per cent phosphorus, and 6.78 per cent moisture. This mine was one of the very few limonite mines of the region from which shipments of carbonate iron ore was made. This ore is described below (p. 63).

The Wharton mine has probably yielded a larger production than any other limonite mine in the Cambrian quartzite of the Allentown quadrangle. The total production seems to have been more than 200,000 tons. Statistics for only the later years in which the mine was worked are available.

Production of Wharton limonite mine.

Year	Tons	Average iron content
1890	498	57.70
1900	2,616	53.02
1901	6,147	50.59
1902	2,074	42.56
1903	2,096	42.85
1904	6,141	37.26
1905	3,405	38.90
1906	4,315	37.59
1907	3,478	38.36
1908	4,833	40.91
1909	5,194	42.17
1910	3,986	42.03

In 1901 in addition to the limonite there were 252 tons of carbonate iron ore shipped and in the following years 104 tons.

129. Koch mine.—The Koch mine was an open-cut mine located a short distance east of the Wharton mine. It was extensively worked first by the Saucon Iron Co. and later by the Thomas Iron Co. The main body, which was almost flat, had a width of 2 to 3 feet but the larger part of the product of the mine consisted of "wash ore" that was distributed through the clay.

The ore was low in iron, averaging only about 31.94 per cent and 0.927 per cent phosphorus and 2.48 per cent manganese.

During the last period of operation, from 1902 to April 15, 1907, the mine produced 20,753 tons of ore, all of which was hauled to the Hellertown furnace.

130. Emery or Beatty open-cut mine.—This mine adjoins the Koch mine on the east and contains the same kind of ore. The ore was high in phosphorus, averaging about 1 per cent. The open cut and shaft together produced about 20,000 tons of ore. The mine was closed in 1890. Pebbly Cambrian quartzite which strikes N. 40° E. and dips 78° NW., outcrops on the south side of the pit.

131. Emery or Beatty mine shaft.—This shaft, about 50 feet in depth, is located some distance east of the open pit. Good ore was obtained.

132. Geisinger's mine.—Geisinger's mine is a pit about 40 feet in depth which shows no rock in place. There is little doubt that the ore occurs in the Cambrian quartzite.

133. Haupt's iron mine.—Very extensive mining has been done at Haupt's iron mine both by shafts and open cuts. The mine was opened in 1853 and was in operation in 1870. One company is said to have mined 100,000 tons of ore, and another company operated the mine later. Umber and ocher were encountered but were not utilized to much extent until recent years when umber has been dug in a nearby pit.

Iron Carbonate (Siderite) Ore.

Considerable iron carbonate ore is present in the lower workings of many of the limonite mines, both in the limestones and the quartzites, and its occurrence and origin have been already discussed. It is well, however, to call attention specifically to the importance of this class of ore in the Allentown quadrangle, for it has been ignored

by many persons who have studied the limonite deposits of the Appalachian region. It has been found in almost every place where mining has been carried on within recent years and exposures are good.

The iron carbonate ore is gray and occurs mainly in the form of extremely dense, tough, rounded concretions, the largest of which are 6 inches in diameter. Bombshell carbonate ore in which the cavity is filled with white clay also is common. On exposure to the air the ore changes to limonite and the nodules or bombshells readily crumble.

Most of the carbonate ore as mined was associated with so much limonite that it was shipped as ordinary ore. A few mines, however, made occasional shipments of carbonate ore. The Wharton mine, southeast of Hellertown, reported the shipment in 1901 of 252 tons of carbonate ore that averaged 36.74 per cent iron and in 1902 of 104 tons. A complete analysis of carbonate ore from this mine is quoted below:[42]

Analysis of iron carbonate ore from the Wharton mine.

[A. S. McCreath, analyst.]

Protoxide of iron	54.385
Sesquioxide of iron	1.071
Protoxide of manganese	3.254
Protoxide of cobalt	.010
Alumina	1.457
Lime	.540
Magnesia	.540
Sulphuric acid	.112
Phosphoric acid	.263
Carbonic acid	35.340
Water (by difference)	.923
Insoluble residue	2.105
	100.000
Iron	43.050
Manganese	2.521
Sulphur	.045
Phosphorus	.115

MAGNETITE IRON ORES.

Distribution.

Magnetite is widely distributed throughout the pre-Cambrian gneisses of the quadrangle as a rather abundant rock-forming mineral. Locally it is segregated in the form of iron ore, which can be picked up as float rock in hundreds of places on the mountain. There are scores of shallow pits in the mountains where prospectors have tried to locate veins of magnetite ore, and specimens about these openings commonly indicate the presence of some good ore, though

[42] Pennsylvania Second Geol. Survey Rept. MM, p. 188, 1879.

it may be of no commercial importance. Also after heavy rains patches of magnetite sand derived from magnetite-bearing rocks or magnetite veins are commonly seen in the gullies on the lower slopes of the mountains that are composed of gneiss. Sand of this character is especially abundant along the base of the moutain between Colesville and Vera Cruz. Careful exploration by means of magnetic surveys and the digging of trenches or shallow shafts may determine the location of other veins of magnetite as valuable as those that have been worked.

Reports are current that magnetite mines were operated in numerous places in the quadrangle where at present no data can be obtained, but as far as can be ascertained the 19 locations shown on the map are the only places where there has been any mining of consequence. By far the most productive region is that extending for 1½ miles along the south side of South Mountain north of Vera Cruz station. The mines in that region have produced about 300,000 tons of ore and are by no means exhausted. One of them was reopened and worked for a short time about eight years ago.

Occurrence.

The ore of the Vera Cruz region occurs in the form of tabular bodies, generally called veins, which have a maximum width of 15 feet and dip to the south or southeast at angles of 45° to 55° and strike approximately east. The veins do not maintain a uniform thickness in any of the mines but narrow and widen along both the dip and the strike and in places pinch out altogether. In most places the veins are parallel to the bands in the inclosing gneiss, but in some places they do not maintain this attitude. Though most of the veins are in the lighter-colored gneisses, some are associated with the dark basic gneisses, and the same vein may pass from one kind of gneiss to the other without at all changing its character, as is well shown near Vera Cruz station.

In most places the ore body is sharply delimited against the inclosing wall rock, but in some places the transition is so gradual that it becomes difficult to determine the limits of the vein. Small veinlets of magnetite that form offshoots from the vein commonly penetrate some distance into the wall rock, which in most places carries some disseminated magnetite. In Jobst's tunnel, northeast of Vera Cruz station, the wall rock between two veins for a distance of over 250 feet contained from 15 to 25 per cent iron.

In the Vera Cruz region, the only place where exact data have been procured, it was long known that three veins, roughly parallel in direction, extended for a considerable distance along the mountain. When a magnetic survey of a portion of that region was made some years ago by Tobias Castelane under the direction of Thomas A.

Edison it was found that seven veins were present, four of which extend for distances of half a mile to $1\frac{1}{2}$ miles. On the magnetic map (Pl. III) two of these veins are seen to unite. The other veins are short and apparently contain little workable ore.

In some of the mines, particularly the Wickert, the vein was offset by a few small faults, but the continuity and parallelism of the major veins indicates little displacement.

The ore continues to the lowest depths reached by mining; in fact, in several mines the ore improved in quality and the veins widened in the lowest levels, and there is little doubt that the ore bodies extend as deep as profitable mining can ever be done.

Character and Composition.

The magnetite ores in the region are usually known as the "hard ores" or "rock ores" to distinguish them from the brown iron ores. Except near the surface, where weathering has removed the pyrite and decomposed the feldspar the ore is compact and hard but so brittle that it breaks readily. Many different kinds of ore specimens can be obtained, even in a single mine.

The most abundant variety of ore shows somewhat indistinct laminations, which differ in the quantity of gangue minerals present. These layers are from a quarter to half an inch in thickness. In some mines considerable ore consists of alternating layers of quartz and magnetite that suggest crustification, such as occurs in veins formed in open fissures. The bands of pure quartz are as much as three-quarters of an inch thick in some places.

The magnetite occurs in some ores as irregular grains which show parting planes, but in most ores there is a tendency for it to form in lenses or layers, especially in those ores that consist mainly of quartz and magnetite. Some of the magnetite which is present as interlocking grains with the gangue minerals or included within the quartz is clearly older than other particles which form small veinlets that cut across the gangue minerals.

Quartz is by far the most abundant gangue mineral, and much of the ore consists almost exclusively of magnetite and quartz. The quartz is mostly clear and has a slight bluish tint. It occurs as single irregular grains or as lenticular or veinlike bands with a fine granular texture. Many small grains of magnetite are included in the quartz, and in places the quartz is cut by thin bands of pure magnetite.

Feldspars, mainly white or light-green plagioclase but also some orthoclase, are common constituents of the gangue and occur in the form of irregular grains or as slightly elongated lenses or "augen."

Pyrite is abundant in places and shows a tendency to form rims about grains of quartz or to occur as thin streaks along joint planes, although irregular grains of it are disseminated throughout much of the ore. Hornblende is an abundant constituent in the ore in certain places but is practically absent in most of the ore. Much of the hornblende has altered to chlorite. Coarse hornblende is common in the wall rock that adjoins the ore. Biotite occurs in about the same manner as hornblende but is somewhat more abundant. Bands in which biotite is the most abundant constituent are common in highly laminated ores, especially in contact with the streaks of fairly pure quartz. Ilmenite can seldom be detected, but some of the analyses show a rather high percentage of titanium.

Analyses of the magnetite ores of the quadrangle show approximately the following ranges and averages:

Analyses of magnetite ores of Allentown quadrangle.

	Range	Average
Fe	29.00 to 55.00	42.00
SiO_2	15.00 to 44.00	35.00
P	.03 to 1.528	.054
S	.007 to 1.05	.07
Mn	.00 to .03	.01

The wall rocks in the vicinity of the Vera Cruz ore masses contain considerable magnetite and perhaps average 18 per cent iron. Edison had hoped to be able to concentrate profitably both the magnetite of the rocks as well as that of the veins and calculated that in the area mapped magnetically there was about 20,000,000 tons of ore above water level. However, the mill which was erected at Edison, N. J., to concentrate similar ores magnetically did not prove a success, and the whole project was abandoned.

Origin.

So much has been written in regard to the origin of the magnetite ores of the pre-Cambrian rocks of the eastern United States that it would be impracticable here to review all the theories that have been proposed. This work has been ably done by W. S. Bayley.[43]

The light and probably the dark gneisses associated with the magnetite ore bodies are igneous in character, although in the main the dark gneisses of the quadrangle are believed to be of sedimentary origin. These rocks in the vicinity of the magnetite veins contain much magnetite in the form of disseminated interlocking grains that are certainly of primary origin and were formed when the igneous magma solidified from fusion. Subsequently aqueo-igneous products of differentiation from the subterranean magma, consisting of greater

[43] Bayley, W. S., Iron mines and mining in New Jersey: New Jersey Geol. Survey, vol. 7, pp. 147-193, 1910.

amounts of quartz and magnetite and lesser amounts of feldspar and ferromagnesian materials, were intruded within the cooled rocks. These intrusions came up in the form of sheets, which broke through along roughly parallel lines, owing to stresses or actual breaks in the rocks that were brought about by some force which acted in one direction and weakened the rocks in parallel lines sufficiently for the later magmas to come toward the surface. The materials brought up were probably in solution in gases or highly heated waters, which penetrated the country rock in many places and injected into them additional magnetite to that which they already contained. Many of the country rocks are injection gneisses, as shown by the relation of some of the magnetite to the other minerals, yet it is doubtful whether all the magnetite of the associated gneisses originated in this manner.

The underlying magma continued to differentiate, and during some later period, or perhaps during several periods, earth stresses forced some of the magmas to the surface As the places of earlier intrusions were the weakest places in the overlying rocks the later solutions came up through the earlier intruded rocks. In the process of differentiation the solutions that came to the surface at times contained almost pure quartz and at other times practically nothing but magnetite, a difference which accounts for the pure veinlike masses of these minerals that are commonly seen. In places a vein of magnetite cuts the quartz, but elsewhere the relation is reversed. Some pyrite was also present in some of the aqueo-igneous solutions, and its relation to the other minerals shows that it was formed after most of the minerals of the ore body had solidified.

As the later intrusions took place the earlier intrusions were enriched by magnetite and quartz, which replaced some of the silicate minerals, such as feldspar, hornblende, and biotite, of the earlier intrusions. There was a tendency for the hornblende and biotite to recrystallize in larger grains adjoining the passageways for the solutions as is shown by many specimens collected in the region.

If this explanation of the origin of the magnetite ores of this quadrangle is correct, and it seems to explain the phenomena observed better than any other known hypothesis, the ore bodies owe their origin entirely to ascending aqueo-igneous solutions; hence the ores should continue to great depth without any marked change in either quality or quantity. They surely extend much deeper than it would ever be profitable to mine them.

Methods of Mining.

In mining the limonite ores open-cut methods predominated, but in mining the magnetite ores very little open-cut work was practicable The dipping beds of ore a few feet in thickness which were inclosed in hard rocks necessitated shaft mining almost from the start,

although some open-cut mining has been done in the region to the depth of 20 to 25 feet. Most of the shafts were sunk in the veins and were inclined to the south at angles of 45° to 55°. From the shaft levels were driven to either side and the ore was removed by underhand stoping. In one place a tunnel was driven into the hill to cut the vein of ore 135 feet below the surface. Although the tunnel was serviceable for drainage, it was never used for removing ore, which was hoisted through a vertical shaft to the top of the mountain.

The wall rock in most mines was very firm, so that little timbering was required, even for the shafts. As the depth increased the water became abundant but was not so serious an obstacle as in the limonite mines, because of the location of the magnetite mines higher up on the mountain slopes and the greater solidity of the inclosing rocks. However, in mining limonite some water was required for washing the ores, whereas in the magnetite mines the water was purely a disadvantage.

Some of the ore when brought to the surface was cobbed to remove the leanest materials but received no further treatment. It is said that the cost of mining the ore ranged from $3.50 to $4.00 a ton and it was sold for $5 to $6 a ton. Almost all of it was hauled from the mines to nearby furnaces or to the railroad to be shipped.

Most of the mines were operated by the owners, who sold the ore wherever they could. A few mines, however, were controlled by iron companies that owned furnaces and were leased on a royalty with the arrangement that all the ore should be brought to their furnaces and paid for at prevailing market prices. The royalty ranged from 20 to 50 cents a ton.

Economic Considerations.

For many years the magnetite mines of the quadrangle have been worked only in a small way if at all, and some of the last ore mined long remained unsold. So far as known, the ore was not exhausted in any of the mines but instead in some of them was more promising when operations ceased than it had been previously. The present condition, in which only one mine has been in operation during the last decade, seems to be due in part to the small and uncertain output, which was neither large enough nor sufficiently regular to appeal to iron manufacturers, and in part to the quality of the ore in comparison with other ores that are shipped into the district from other iron districts. The large amount of silica in the ore is especially objectionable, and the iron content is considerably lower than that of the Lake Superior, northern New Jersey, or Adirondack ores.

The only hope for the future of magnetite mining in this area seems to be in a change of plans by which the production would be

largely increased and concentrating mills erected. The ore could be concentrated magnetically with ease, and the product obtained should find a ready market at the furnaces still in operation in the immediate vicinity. It is not at all improbable that the tailings, which would consist almost entirely of angular quartz particles, might be sold for concrete and road metal for a price sufficient to pay part of the cost of concentration. Unless the ore is concentrated it is questionable whether any of the magnetite mines of the quadrangle can be profitably operated under existing conditions.

Magnetite Mines.[44]

134, 135, and 136. These mines are southeast and east of South Bethlehem and seem never to have been worked actively. They were probably little more than prospects.

137. In a trial pit 1 mile south of Lower Saucon Union Church 2 feet of ore was discovered but was not of sufficient importance to mine.

138. The Emaus Iron Ore Co's. mine, formerly known as the Hildegast or Shelly mine, is on the First or Front vein at the extreme west edge of the quadrangle north of Vera Cruz. It seems to have been first opened 35 to 40 years ago for the Coleraine Iron Co. of Redington. It has been worked at several different times. It was acquired by the present company in 1914 and in 1915 they were engaged in cleaning and retimbering it preparatory to working. All work soon ceased. This mine is the only iron mine of any kind recently operated in the quadrangle.

The shaft, which is sunk along the vein, is said to be 100 feet deep and the ore body from 3 to 5 feet thick. The ore, which is of fair quality, contains much clear quartz and small amounts of pyrite, hornblende, and feldspar.

139. The Moyer mine, which is on the Third Vein, was first worked about 30 years ago. It was last worked by James Hosking about 1897. The shaft is 60 feet deep; drifts have been run about 100 feet both east and west of the shaft. The ore averages about 45 per cent iron. It is estimated that the mine has produced about 10,000 tons. The ore and vein are similar to that found in the Wieand mine.

140. The Wieand or Mann mine was worked before the Civil War and is the oldest magnetite mine in the region. It has two shafts about 75 feet in depth. The vein is 5 to 6 feet thick. The ore is finegrained and contains considerable feldspar and mica as well as quartz. Drifts were run about 150 feet both east and west of No. 1 shaft. It has been estimated that the mine has produced approximately 100,000 tons of ore. Much of the ore was shipped to the Crane Iron Co.

141. Fink mine has a shaft that is said to be 80 feet deep. It is on the Third vein, and the ore is similar to that of the Moyer and Wieand mines. The vein ranges from 4 to 8 feet in width. The mine produced 5,000 to 6,000 tons of ore, which was shipped to the Bethlehem Iron Co.

142. The Wickert mine, which was earlier known as the Bader mine, was opened about 1880. It was last worked by James Hosking in 1910. There are four shafts on the property, two of which are about 200 feet in depth, and several open cuts. Drifts have been run along the vein for a distance of several hundred feet. The vein which is known as the Second or Back vein, is 5 to 14 feet wide and shows a decided tendency to widen and pinch both along the dip and strike; in places ore was absent. The vein dips about 55° S. and strikes almost due east. Some faulting has offset the vein, making it appear as two veins. In the upper levels the ore averages about 45 per cent iron, but in the deeper levels it contains from 50 to 55 per cent iron. A sample which had been exposed on the dump for about 20 years was analysed in the laboratory of the Bethlehem Steel Co. with the following results:

Analysis of magnetite ore from Wickert mine.

Fe	37.51
Mn	.00
P	.023
S	.012
SiO_2	33.07

[44]The numbers given to the mines in this description refer to the numbers on the map (Pl. II, in pocket).

The ore is mainly a mixture of magnetite and clear quartz, which iu places occur in the form of thin alternating bands, but in other places the two minerals are in intimate association in a granular mass.

The method of working was to run drifts aloug the vein and then stope down on the ore. At oue time two shafts were employed in the mine, and for about four years there were about 60 men in the employ of the company. The mine has produced from 60,000 to 65,000 tons of ore. Several hundred tons of ore are now on the dump awaiting a market.

143. At the Swartz mine several opeu cuts and shafts were opened about 1884. At the depth of 25 feet in one of the shafts which is 55 feet in depth a drift was driven 6 feet to the east and another 15 feet to the west. The mine is located on the First or Front vein, which is here about 5 feet thick and has a seam or "horse" of rock in the center from 6 to 12 inches thick. The ore is finegrained and coutains considerable pyrite. The mine is said to have produced about 3,000 tons of ore, which was shipped to the Bethlehem Iron Co. Two samples from the dumps that were analyzed by the Bethlehem Steel Co. iu 1906 gave the following results:

Analyses of magnetite ore from Swartz mine.

	1	2
Fe	35.00	43.00
Mn	.00	.01
P	.056	.066
S	1.048	.191
SiO_2	38.55	32.00

An old shaft was sunk on the Third vein just east of a new road that is not shown on the map. It is now completely filled and is reported to have been 30 feet in depth. The ore found was leaner than that in neighboriug mines.

145. A shaft on the Second or Back vein is on the west side of a road that is not shown on the map. The material on the dump contains pieces of a very basic gneiss, which seems to have been associated with the ore.

146. The Engelman mine comprises a shaft, which is commonly supposed to be on the Second or Back vein, a short distance west of Jobst's miue. The magnetic survey chart (Pl. III) shows, however, that it is on a slightly different vein but one which unites with the vein worked in Jobst's shaft and tunnel. Little is known of this mine.

147. At the Jobst mine in 1875 a tunnel was run into the hill from the road by the Hellertowu Iron Company. At a distauce of 150 feet from the entrance a 4-foot body of ore known as the Front or First vein was penetrated and at 411 feet the Secoud or Back vein was found. The Front vein, which coutains solid ore of good quality, was never mined. The Back vein was extensively mined. From the eud of the tunnel a shaft was driven upward to the surface, a distance of 135 feet. This shaft was also continued downward 75 feet below the tunnel level. The Back vein at the tunnel level was 6 feet thick, but at the bottom of the shaft it was 8 to 15 feet thick aud contained solid ore of good quality. Above the tuunel level the vein was only about 2 feet thick, too thiu to be worked with profit. The vein dips to the south at an angle that averages 45°. The ore contains considerable hornblende and pyrite.

Tobias Castelane, who investigated the Vera Cruz mines for Thomas A. Edison, sampled the rock in the tunnel between the two veins aud found that it eontained from 15 to 25 per cent iron.

The ore was stoped along the Back vein below the tunuel level to a distance of 300 feet along the strike and hoisted to the surface through the shaft.

About 40,000 tons of ore was produced from this mine, most of which was shipped to the furnaces at Hellertown, Emaus, aud Edgehill.

148. No information is available regarding the Bachman mine.

149. Nothiug is known concerning this mine, which was probably only a prospect hole.

150. The Eichelberger & Frey mine is 1 mile west of Spring Valley on the farm of W. J. Sleifer. Magnetite ore was mined at this place for several years prior to 1883. The are two shafts, one of which is reported to be 100 feet iu depth. About 4,000 tons of ore was mined, most of which was hauled to the Bingen furnaee. No data could be obtained in regard to the size and character of the vein. The ore contains much quartz and considerable pyrite, feldspar, and hornblende. The following analyses of ore from the dumps were made by the Bethlehem Steel Co. in 1900 and 1905:

Analyses of [illegible] from Eichelberger & Frey mine.

	1	2
	54.81	35.47
Mn	.02	.025
P	.04	.029
S	.046	.125
SiO_2	21.28	43.68
Cu	----	.002

There is a report that the ore contained considerable titanium but this has not been verified.

151. A short distance west of Spring Valley a tunnel was driven into the hill in search of magnetite ore. It is reported that some ore was found but not enough for profitable mining.

152. At this prospect hole, three-quarters mile south of Springtown, little ore seems to have been found.

ZINC ORE.

The most productive zinc mines of Pennsylvania are at Friedensville, in the Saucon Valley, about 3 miles south of Bethlehem. Although not now in operation, they have contributed largely to the mineral wealth of the region, and the zinc ranks among the most valuable mineral resources of the Allentown quadrangle. These mines have yielded large quantities of high-grade zinc ore in the past and may in the future become an important factor in the zinc production of the country.

Historical Sketch.

Early in the last century an unusual mineral was noted in the surface soil of the farm of Jacob Ueberroth, about half a mile north of Friedensville, but as iron was the only economic mineral known to occur in the region little attention was given to this material. However, about 1830 a wagonload of the unknown substance was hauled to the Mary Ann iron furnace in Berks County to be tested. Naturally the experiment yielded no metal, as all the zinc was volatilized and escaped.

In 1845 Andrew Wittman, after studying Overman's "Metallurgy," conducted some experiments with the ore by means of a small crucible in a stove and obtained a few globules of metal but did not know that it was zinc.

Also in 1845 Theodore William Roepper, a local mineralogist, who later became the first professor of mineralogy and geology in Lehigh University, while taking an afternoon's stroll in the vicinity of Friedensville picked up a few pieces of the hitherto unknown mineral and determined it to be calamine. He conducted experiments in Lehman's foundry, in South Bethlehem, and succeeded in making brass from the calamine and native copper. He did not succeed, however, in making spelter.

Roepper induced Robert Earp, a Philadelphia importer, to examine the deposit and to obtain a lease on the Ueberroth farm. After this

lease was obtained, 9 tons of ore was mined and shipped to England in one of Earp's vessels in January, 1846. The temperature of the English furnaces, which was gaged for roasted ore, was not high enough for the calamine, so the report came back that the ore could not be used.

Experimentation was carried on in this country and finally a process was developed for the manufacture of zinc oxide from the calamine ore. In the spring of 1853 Samuel Wetherell began the construction of furnaces for the production of zinc oxide according to a process of his own invention. The furnaces were erected in what is now the south portion of Bethlehem (then known as Augusta) and had a capacity of 2,000 tons a year. They were completed on October 12, 1853, and on the following day zinc oxide was produced from the Friedensville ore by the "furnace" and "tower" process of Wetherell and collected by the "bag" process of Richard Jones. The operation was described by M. S. Henry[45] as follows:

> The entire process of manufacture practised here consists, in effect, of the following operations, viz.:
>
> The ore, pulverized and mixed with coal, is strongly heated in furnaces which are fully supplied with air; the metallic zinc which is thereby extracted in the form of vapor, is instantly oxidized, and the oxide of zinc thus formed, being an exceedingly light powder, is carried immediately from the furnaces by a strong artificial draft, together with large quantities of gases, and such ashes, etc., as are light enough to float in a current of air. These ashes are taken first and separated and deposited with the coarse particles of zinc oxide in rooms provided for the purpose; a part of the pure zinc oxide is afterward caught in chambers, and finally the gases are all strained out by an immense apparatus of flannel and muslin bags, to the inner surface of which the last and finest of the zinc oxide adheres, whence it is removed at proper intervals.
>
> The zinc oxide which is thus collected in the chambers and bags, is in the form of a very white, fine, and flocculent powder, which is compressed by proper apparatus into much smaller bulk, and is then carefully packed into strong, tight, paper-lined casks.

The manufacture of zinc oxide from the Friedensville ore was the second successful attempt in the United States. In 1852 the New Jersey Zinc Co. in its works at Newark, N. J., had begun the manufacture of zinc oxide on a commercial scale. Its output for 1852 was 1,083 tons, and for 1853 it was 1,805 tons; altogether only about 2,500 tons had been produced in the country before the beginning of operations at Freidensville.

On May 2, 1855, by an act of the legislature, the Pennsylvania & Lehigh Zinc Co., composed of the same men who had already begun operations, was incorporated with a capitalization of $1,000,000 "for the purpose of mining zinc ore in the counties of Lehigh and Northampton, of manufacturing zinc paint, metallic zinc, and other articles from said ore, and of vending the same."

Attempts to produce spelter were early made, and between 1854 and 1859 Wetherell carried on a series of experiments for that purpose. He succeeded in producing spelter, but the process he developed was

[45] History of the Lehigh Valley, pp. 236-237, 1860.

not economical and the experiments were discontinued. His method was to heat the ore in the open furnace and then draw the fumes of zinc oxide through incandescent anthracite to reduce the oxide. He made a few tons of spelter in this way.

In 1857 Matthiessen and Hegeler, two young men fresh from the School of Mines of Freiberg, Saxony, obtained permission to experiment in the plant which the company had erected at Freidensville. They were successful in making spelter but were not able to make satisfactory terms with the company for the erection of a plant of practical size

In 1859 Joseph Wharton contracted with the company for the erection of spelter works of the Belgian type, with retorts made of materials that had been found to be sufficiently refractory, and brought to this country Louis de Gée, of Ougré province of Liége, Belgium, to superintend their construction. The Belgian furnaces were successful, and in July, 1859, the first spelter was produced.

In 1838, at the United States Arsenal in Washington, the first brass was produced in this country. The zinc was made from a mixture of zincite ore of Franklin Furnace and Sterling Hill. Zinc ore from the Perkiomen lead and zinc mine in Montgomery County, N. J., was used in the manufacture of the standard weights and measures ordered by Congress. The method was the one employed for hundreds of years in producing brass from copper and zinc ore. The process, however, was so expensive that it was many years before any attempts were made to utilize the zinc ores of this country.

Up to this time spelter had been made commercially at only one place in the country. The first regular manufacture of spelter was started in 1850, and the New Jersey ores were used. The industry did not meet with much success for several years, because the oxide of iron in the franklinite of the ore formed a fusible silicate with the siliceous matter of the clay. Thus the production of spelter from the Friedensville ores was started only a few years later than that from the New Jersey ores, and the furnaces erected at South Bethlehem were the first entirely successful zinc furnaces in the United States.

On February 16, 1860, by an act of the legislature the name of the company was changed to the Lehigh Zinc Co., the name by which it is best known. There was much litigation concerning the ownership of the property until 1861, when the company purchased the land outright.

In 1864 and 1865 the company erected a mill for rolling sheet zinc with a capacity of 3,000 casks or 1,680 tons a year. The mill started operations in April, 1865.

From 1853 to 1876 the Lehigh Zinc Co. continued to operate its Friedensville mines without interruption. From the beginning of

operations until 1875 this company was the only operating company in the district. However, it never owned the property of the Jacob Correll estate, which lies just west of the Friedensville Church. This property was originally leased by the Passaic Zinc Co., by which it was sublet to the Lehigh Zinc Co. on high royalties. In 1875 on the expiration of this lease, the Bergen Point Zinc Co. of Bergen Point, N. J., obtained the lease and began operations. For about a year, therefore, until the discontinuance of the Lehigh Zinc Co's. operations, there were two companies at work in the region. The Bergen Point Zinc Co. continued to operate until 1881.

In 1881 Franklin Osgood, who already owned an interest in the Correll mine, purchased the Lehigh Zinc Co's. property, consisting of the Ueberroth, Old Hartman, and New Hartman mines, and organized the Friedensville Zinc Co. New smelters were erected at the Ueberroth mine and oxide works at the Hartman mine. However, from 1881 to 1885 the ores mined were mainly shipped to Bergen Point, N. J., but after March, 1886, they smelted at the works.

Mining operations at the Correll and New Hartman mines continued with few interruptions to November, 1893, since when all the mines have been idle. The Ueberroth mine was worked for a while in 1883 and again for a short time in 1886. The big pump of this mine was run from September 29, 1890, to September 15, 1891, but merely for the purpose of lowering the water in the New Hartman mine.

At present the New Jersey Zinc Co. owns all the mines that have thus far been opened, except the Correll mine, together with considerable land adjoining. Prospect drilling by this company was carried on in 1914 and 1915 in the vicinity of the Old Hartman mine and later water was pumped from the New Hartman mine for several months and the shaft repaired but no ore taken out. Conditions brought about by the war interfered with the operations and all work ceased. In 1923 drilling was resumed and is still in progress.

It is estimated that 50,000 tons of spelter and 90,000 tons of zinc oxide, valued at approximately $20,000,000, have been produced from the Friedensville zinc ores. Only incomplete statistics of actual production have been obtained from occasional items in the mining journals.

From October, 1853, to September, 1857, the production of zinc was 4,725 tons.

In 1865 the production amounted to approximately 3,000 tons of zinc oxide, 3,600 tons of metallic zinc, and 3,000 casks or 1,680 tons of sheet zinc, which represented about one-half the total production of the country. The president of the Lehigh Zinc Co. stated in 1872 that in certain years 17,000 tons of ore was mined and that up to that time about 300,000 tons had been taken from the ground.

In 1875 the Bergen Point Zinc Co. produced 500 tons of spelter and 1,000 tons of zinc oxide from the ores of the Correll mine and the Lehigh Zinc Co. 1,505 tons of spelter from ores obtained from the Ueberroth and Hartman mines.

From 1876 to 1881 the Correll mine is said to have produced about 50 tons of ore daily.

The census statistics for 1880 give a production of 20,459 tons of ore for the Friedensville mines.

Distribution.

The area in which ore has been found in paying quantities is exceedingly small, comprising localities in the immediate vicinity of Friedensville and about half a mile to the northwest. Considerable prospecting has been done over a much larger area throughout the Saucon Valley and elsewhere in the Allentown quadrangle but without results. Reports of zinc ore from other places have been circulated at many times but have never been confirmed. Traces of zinc have been found in some limestone drill cores from a locality about 1 miles west of Friedensville, in the limonite iron ores about 1½ miles west of Friedensville, and in the Hellertown Cave.

Character and Composition.

The zinc ores first worked in the Friedensville region consisted almost entirely of calamine, together with some smithsonite, mixed with the residual clay formed by the decomposition of the country rock, which is Ordovician limestone of Beekmantown age. In depth the calamine and smithsonite decreased rapidly, and zinc blende (sphalerite), intimately associated with pyrite and marcasite, became more common.

The calamine occurs in irregular segregations in the clay, in fissures in the limestone, or in the porous, partly silicified limestone, commonly in botryoidal or stalactitic forms. Sheets or plates from 2 to 3 feet square and from an eighth to a quarter of an inch thick are said to have been frequently found in the crevices in the limestone. These masses of calamine were coated with small crystals of the same mineral. The crystals of calamine are small but clear and lustrous. In color the calamine ranges from colorless to yellowish and greenish-blue.

The smithsonite was usually inconspicuous and occurred as white scales or granular masses coating the calamine or blend, or on the walls of the limestone fissures, or as yellowish-brown porous masses. Most of the smithsonite mined was amorphous and occurred in botryoidal, stalactitic, or laminated masses. A few plates of small clear crystals with vitreous to pearly luster were found. White, gray, or colorless crystals are most common, but greenish-white to greenish-

yellow crystals occur. The yellow crystals contain greenockite. Druses of smithsonite coating crystals of aragonite and quartz have been found, showing the later deposition of the smithsonite.

The smithsonite and calamine were formed by oxidation of the sphalerite, but the depths at which the sulphide was encountered in the different mines were not uniform. In the Ueberroth mine, for example, calamine was found at a depth of 200 feet from the surface; a mass weighing 8,500 pounds from that depth was exhibited at the Centennial Exposition. On the other hand, some sulphide ore was found only a few feet from the surface in the Old Hartman and Correll mines. This difference was undoubtedly due to the greater freedom of downward circulation of meteoric water containing oxygen along certain strata which changed the sphalerite to calamine or smithsonite. The vertical and greatly shattered beds of the Ueberroth mine readily permitted the surface waters to pass between the bedding planes to greater depths than in the Correll mine and the Old Hartman mine, where the beds of limestone have a less degee of inclination, and are less broken.

The Friedensville sphalerite or zinc blende is of a peculiar character, essentially unlike any other found in the country. In the main it occurs as compact gray to bluish-black or black masses having a prominent conchoidal fracture and rarely shows any traces of crystallization. It is translucent in thin pieces and produces a clear ring when struck. Much of it resembles in appearance dark-blue limestone, from which it is readily distinguished, however, by its greater specific gravity. Sphalerite of a light resinous color and well crystallized occurs in small veins in the limestone, and less commonly small honey-yellow crystals are found on the sides of cavities in the limestone. As sent to the works the sulphide ore contained from 35 to 40 per cent of zinc. Its noncrystalline structure and the presence of pyrite render its concentration difficult.

Pyrite is almost universally found in association with the sphalerite in massive form. In many places the masses of sulphide consist mainly of pyrite. The large amount of pyrite has been one of the most objectionable features of the sulphide ore. Within the ore crystals of pyrite are extremely rare, but they can be seen in many places in the limestone as small cubes. The ease with which some of the massive iron sulphide decomposes suggests the presence of considerable marcasite, although this has not been definitely determined. Melanterite (hydrous ferrous sulphate) is frequently seen as an efflorescence on the masses of pyrite and marcasite ore.

Greenockite (cadmium sulphide), which occurs in many places in association with sphalerite, is found in the Friedensville mines but in the amorphous form only. It occurs in the form of yellow, greenish-yellow, or orange-colored earthy incrustations on sphalerite,

calamine, or limestone. Roepper also found it in clayey material resulting from the decomposition of pyritiferous limestone. A specimen of this material which he analyzed contained 5 per cent of cadmium.

Goslarite, the hydrous sulphate of zinc, also known as white vitriol, has been obtained in the Friedensville mines in small quantities. It is formed by the oxidation of sphalerite and occurs as incrustations of the sphalerite and as fine needle-shaped white crystals.

A few specimens of hydrozincite, in the form of white mammillary particles or earthy white masses, were found while the mines were in operation. Halloysite, which resembles cloudy amber and has a marked conchoidal fracture, occurs as a rare mineral. The specimens are very brittle and have a low specific gravity.

The mines furnished considerable quantities of a claylike material, in some places known as "tallow clays" but in this region described by Roepper as a new mineral to which he gave the name "sauconite." Genth[46] described it as follows:

Apparently amorphous, fracture conchoidal; streak brown and shining; translucent on thin edges; translucency increased by wetting. When thrown into water emits a crackling sound.

Hardness=1.5; Specific gravity=2.66-2.70.

The following varieties have been analyzed by Roepper: (1) pale yellowish-white; (2) ocher-yellow (after having been dried during one hour at 105°C.). (3) Blake[47] analyzed a pale-yellow variety.

	1	2	3
Silicic acid	48.94	46.45	41.36
Alumina	10.66	7.41	8.04
Ferric oxide	3.85	14.28	9.55
Zinc oxide	26.95	22.86	32.24
Magnesia		0.97	1.02
Lime	2.42		
Potash			trace
Water	7.06	6.73	7.76
	99.88	98.69	99.97

Like all similar minerals, the composition is somewhat variable, owing in part to accidental admixtures and a replacement of one isomorphous substance by another.

Allowing in the first analysis for a mechanical admixture of 3.45 per cent of silicic acid (quartz), the oxygen ratios of zinc oxide and lime (RO) to alumina, and ferric oxide (R_2O_3) to silicic acid and water are 1:1:4:1, corresponding with the formula $3(RO, SiO_2)+R_2O_3, 3SiO_2+3H_2O$.

At one time the Lehigh Zinc Co. obtained a considerable quantity of the "sauconite" in fairly pure form and shipped it to the oxide furnaces. Although the material proved to be satisfactory for the manufacture of zinc oxide no further shipments were made, as it usually was taken from the mine together with the other ore and was washed away in the log washers with the ordinary clay.

[46] Genth, F. A., Preliminary report on the mineralogy of Pennsylvania, Pennsylvania Second Geol. Survey, Rept. B, pp. 120-121, 1875.

[47] Dana's Mineralogy, p. 409, 1868.

Masses of white kaolin are common, although most of the clay contains impurities of various kinds. Quartz is especially abundant and occurs as a result of the metasomatic replacement of portions of the limestone which produces a compact quartzite, as thin veins that cut the limestones in all directions, and as small crystals that line cavities in the somewhat porous altered limestones. An interesting variety of fibrous quartz that has been found in the mines has been called "petrified horsehair." Secondary calcite occurs in many places as cavity fillings and as small crystals. The mines yielded many beautiful specimens of aragonite, which occurred as radiating acicular crystals as much as 1 inch in length in cavities in the limestone. Most of the aragonite contains some zinc. One specimen analyzed by Roepper yielded the following results:

Partial analysis of specimen of aragonite from Friedensville, Pa.

$CaCO_3$	94.20
$ZnCO_3$	4.73
Insoluble material	.53
	99.46

As the limestone that contains the ore is highly dolomitic, secondary dolomite would be expected to occur. Cavities in the limestone lined with characteristic crystals of dolomite are common. Ocherous limonite derived from the original pyrite or marcasite is abundant, and here and there masses of turgite are found. One specimen of ocherous limonite in the Roepper collection in Lehigh University shows beautiful laminated mammillary structure. Pseudomorphs of limonite after pyrite are common in the limestones in close contact with the ore bodies. Impure masses of wad are occasionally seen in association with the limonite.

Asbestos of the variety called "mountain leather" occurs in places in the crevices in the limestones. Allophane in white botryoidal and stalactitic masses is found in small amounts. The region has also yielded a small amount of lanthanite in the form of aggregations of small rectangular crystals that are a delicate pink and have a pearly luster. Although the mineral was reported to have been "thrown out from a few feet below the surface by the miners when sinking an exploring shaft near one of the veins of calamine," it is probable that the specimen originally came from the gneiss a short distance to the north. An analysis by W. P. Blake[48] gave the following results:

Partial analysis of specimen of lanthanite from Friedensville, Pa.

Water	24.09
Carbonic acid	22.58
Oxide of lanthanum and didymium	54.90
	101.57

Cerium was not detected but was probably present.

[48] Am. Jour. Sci., 2d ser., vol. 16, pp. 228-230, 1853.

The ores of the Friedensville region are remarkably free from objectionable minerals, such as those which contain lead, arsenic, and antimony, and for that reason the spelter and oxide made from them always commanded the highest prices. The following notes [49] are interesting in this connection:

Lehigh zinc, or spelter, made from the ores of the Friedensville mines, near Bethlehem, Pa., has a world-wide reputation as the purest zinc in the world, and as specially adapted for use in cartridge making; in fact, it is the only zinc yet known that will make a cartridge that will never expand and stick in the gun in firing. The Russian and Turkish governments long ago recognized this fact, and during their last war had expert commissions in this country testing the metal made into cartridges for them, and they even brought over ores from other countries to treat here, in order to determine whether the high quality was due to any special treatment here. It was fully demonstrated that Lehigh zinc is better than any other because the ore is purer, containing neither arsenic nor lead, and that, with Lake copper, it formed the best cartridge metal yet made. Other European nations have recognized the same fact by buying here; but the English government, with its accustomed "deliberateness," could not accept this fact without expensive experience of its own. Fortunately this experience came in a little instead of a great war. In the Sudan campaign it is said to appear beyond doubt, from evidence collected by Lord Charles Beresford, that in one action with the Arabs 25 per cent of the rifles were at one time useless by the jamming of the Boxer cartridge, and as this no doubt greatly increased the losses of the British, and lacked but little of annihilating the band of heroes who fought their way forward in their vain effort to rescue General Gordon, it has at last attracted the attention of the government, and a contract has been made for a large amount of Bergenpoint Company's Lehigh spelter, with which new cartridges are now being made. The price paid is said to be equivalent of 8¾ cents a pound.

All the famous mines producing this exceptional ore are now owned by the Bergen Point Zinc Co., which has now made contracts to send 2,000 tons of this ore to Belgium for treatment.

Occurrence.

The zinc ores occur in a region of sharply folded and faulted Ordovician limestones of Beekmantown age. The surface covering of residual clay and glacial debris prevents an accurate determination of the structure. The rocks have been greatly shattered by the earth movements to which they have been subjected and have thus been opened to the active circulation of water.

No extensive faults can be determined from the outcrops, none have been described in the literature, and the inaccessibility of the underground workings at present prevents additional observations. Slickensided surfaces can be seen in many places in the Ueberroth and Old Hartman workings, and zones of limestone breccia that seem to be in part if not entirely fault breccia indicate displacements. At the Old Hartman mine the brecciated limestone is especially well shown in the outcropping ledges. Such evidences of movement as can be obtained indicate that the faulting was confined principally to displacements along the bedding planes.

That the rocks of the region have yielded to the intense strain to which they have been subjected is shown by the numerous narrow quartz veins that penetrate the limestones in every direction. So abundant are these quartz veins that in many places areas free of

[49] Eng. and Min. Jour., vol. 41, p. 423, 1886.

them that are more than a few inches in diameter are rare. There can be no question that the shattered condition of the limestones in this region has been the most favorable factor in promoting the mineralization of the area by permitting the active circulation of water.

Less than half a mile north of the Ueberroth mine there is a normal fault that has a throw of more than 2,500 feet by which the Cambrian limestone and quartzite formations have been faulted out and the Ordovician limestone has been brought into contact with the pre-Cambrian gneisses. The direction of the fault is approximately N. 80° E. Another fault that has the same general direction but less throw occurs about half a mile south of Friedensville. It is also probable that a parallel fault passes between the Ueberroth and Correll mines, with the Ueberroth and Old Hartman mines on the north side of the fault and the New Hartman, Correll, and Three Corners mines on the south side. This relation would explain the great discordance of dip of the strata at the different mines. The limestone strata and the main ore veins are practically vertical at the Ueberroth and Old Hartman mines, whereas at the other three mines, which are in a line about N. 80° E., the principal ore veins and inclosing limestones dip 35-45° S.

The whole of the Saucon Valley, which is about 7 miles long from east to west and from 2 to 4 miles wide, is a region in which the structure of the rocks is complicated and in which close folding and faulting have shattered the rocks to great depths, although in no other place in the valley have the rocks suffered to the same extent as in the vicinity of Friedensville. The lines of structure in general trend northeastward, parallel to the general trend of the valley and to the ridges of gneiss on either side.

The more persistent veins are conformable with the bedding planes of the limestones and consist either of ore which filled openings between the beds that had been enlarged by solution or locally of sphalerite and pyrite that replaced the limestone and that near the surface have been altered to calamine, smithsonite, and limonite. The accompanying view of the east side of the open pit of the Ueberroth mine (Pl. V) shows the vertical limestone strata and the open fissures from which the ore has been removed. In places the veins were as much as 20 feet in width, although in the main they were much narrower. They differed greatly in width from place to place, even though they were continuous for great distances.

The veins that follow the joints are approximately at right angles to the principal veins and thus break the limestone into more or less rectangular blocks, which in the Ueberroth mine, where the strata are nearly vertical, was a serious drawback to mining on account of the falling of great masses of limestone on the removal of the ore.

The strike and dip of the main ore veins are fairly regular in each of the mines, and the ore bodies pitch to the southwest along the strike at an angle of about 20°, as determined in the workings of the Correll and New Hartman mines. The main view of the Correll mine, which was exposed in the open cut, did not come to the surface in the New Hartman mine, but instead its highest point lay at a depth of 110 feet. The main veins of the Ueberroth mine also seem to pitch westward. Although considerable prospecting has been done east of the Friedensville-Colesville road, along the strike of the main Ueberroth veins, no ore has been found.

The veins parallel to the limestone strata, which strike N. 80° E., were remarkably persistent. The Stadiger vein in the Ueberroth mine was worked along the strike for a distance of about 1,000 feet. On the other hand, the cross veins that follow the joints, which have an average strike of N. 10° W., were comparatively short. Where the two sets of veins intersected, the ore bodies were largest and richest. Some of these masses of ore were as much as 60 by 20 feet in cross section.

The vertical extent of the ore bodies has not been determined, as ore was found at the greatest depth explored, which was about 300 feet at the New Hartman mine.

The oxidized ores, which have been practically exhausted in both the Old Hartman and the New Hartman mines, occurred near the surfaces in deep pockets that were formed by solution in the limestones and were associated with residual clay. In the Ueberroth mine they persist to the greatest depth reached, probably in relatively diminished quantity but unchanged in quality. At lower depths, however, they occur, together with some of the blende, as the fillings of fissures in the limestone which have been formed through the enlargement by solution of openings between bedding planes or joint planes, but the blende is mostly a product of metasomatic replacement in all the mines.

In some of the parallel veins that are only short distances apart the blende was found almost at the surface, whereas in others the oxidized ores were abundant at depths of 200 feet. This irregularity was a serious drawback in the working of the mines, as it was inadvisable to mix the two classes of ore.

Origin.

The origin of the Friedensville zinc deposits has long been in dispute, and there is a justifiable difference of opinion regarding the explanations that have been offered. Drinker[50] supposes "that the zinc was originally disseminated through the dolomite in the form of carbonate or sulphide." Later the small particles were dissolved

[50]Drinker, H. S., Am. Inst. Min. Eng. Trans., vol. 1, pp. 67-68, 1873.

by water that contained carbonic acid, converted into zinc sulphate by coming into contact with sulphuric acid that was formed by the decomposition of pyrite, and were later precipitated in their present location as zinc sulphide through the action of the animal matter contained in the limestones.

Lesley[51] held somewhat similar ideas and said that "it is probable that they [lead and zinc minerals] were deposited with the limestone in far greater abundance in ancient ages and were originally brought into the Appalachian sea as soluble salts, together with the lime and magnesia waters of the primeval rivers," and that "the dissolution of the lime rocks has produced concentrated masses of zinc ore." He compared the zinc ore to the residual deposits of limonite which are found in the same rocks but had no explanation for "zinc being substituted in the place of iron."

Clerc[52] suggested a deep-seated origin in his published statement that "they belong to a class of deposits which seem to warrant a belief in their continuance to a considerable depth."

Kemp[53] says that "the veins were evidently filled by circulation from below that brought the zinc ore to its present resting place in the shattered and broken belt."

In forming a theory to account for the formation of the sphalerite, pyrite, and marcasite the connection between the Friedensville zinc deposits and the limonite ore deposits that occur elsewhere in the Saucon Valley should be recognized. Lesley suggested such a connection but did not enter into details. In the iron mines that lie about 1½ miles west of the zinc mines considerable pyrite was found in the lower depths worked, and more would undoubtedly have been found had operations continued. The mines, however, were abandoned on the closing of the zinc mines, as only the pumping of the zinc mines lowered the water in the iron mines and made mining practicable. The iron deposits themselves were not rich enough to justify the pumping necessary to work them. Small amounts of zinc were also present in the iron ores of these mines.

The primary source of the pyrite and sphalerite must have been the crystalline rocks of pre-Cambrian age, most of which were originally igneous. Pyrite and magnetite are common minerals in the pre-Cambrian gneisses throughout the southeastern part of Pennsylvania. Zinc minerals, however, have not been recognized in these gneisses, but there can be little doubt that zinc in some form was present in the ancient rocks that furnished the materials for the thick Paleozoic sediments of this section. In the long ages during which several thousands of feet of Cambrian and Ordovician lime-

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[51] Lesley, J. P., Pennsylvania Second Geol. Survey Summary Final Rept., vol. 1, pp. 436-439, 1892.

[52] Clerc, F. L., U. S. Geol. Survey Mineral Resources, 1882, pp. 361-365, 1883.

[53] Kemp, J. F., Ore deposits of the United States and Canada, 2ed., pp. 250-251, 1906.

stones were deposited the iron and zinc minerals must have been carried into the sea and there precipitated in minute disseminated particles in the limestones as sulphides and carbonates. Many of the limestones show small particles of pyrite, and analyses indicate that they contain considerable iron carbonate. The zinc was probably precipitated as a sulphide, although part of it may have been precipitated as a carbonate.

Though much of the iron and zinc may still be disseminated in the limestone these substances have locally been concentrated by circulating water. In the Friendensville district this action has taken place. The limestones of the Saucon Valley probably contained larger amounts of zinc and iron originally than other deposits of equal extent, for traces of zinc are more common in the limestones of the Saucon Valley than in those elsewhere in the Allentown quadrangle.

The waters that concentrated the sphalerite, pyrite, and marcasite were doubtless mainly of meteoric origin, for the only post-Ordovician intrusive rocks in the whole region are the Triassic diabase dikes exposed near Coopersburg, about 4 miles distant. Neither these rocks nor the underlying magma from which they were derived are likely to have been the source of magmatic waters which to any large degree segregated the Friedensville sphalerite and pyrite.

If the deposits were formed by meteoric waters it is of practical importance to determine whether the concentration was effected by ascending or descending waters. If descending waters were the agents of transportation the deposits should not extend much below the ground-water level, whereas if they were formed through the agency of ascending waters they may continue to great depths. At present the ground water level lies within 30 feet of the surface in the vicinity of the mines. As the ore deposits have been explored to a depth of 300 feet and give every indication of continuation to greater depths, ascending waters must have brought the sphalerite and pyrite to their present position unless the ground-water level formerly lay at much greater depths than now.

Throughout the limestone areas of the Allentown quadrangle water rises in many places under artesian pressure along fault planes and zones of rock shattered by intense folding. Perhaps most of the springs in the quadrangle have been formed in this way. Flowing wells have also been obtained in many places and indicate the presence of ascending currents of meteoric water. The temperature of none of these waters is high enough to warrant the use of the term thermal in describing them, yet they maintain a uniform temperature throughout the year and are slightly warmer than the average surface waters, and thus they indicate a fairly deep-seated circulation.

The writer believes that in the formation of the Friedensville zinc deposits downward-percolating waters that contained carbonic acid, which was derived from the atmosphere and organic matter, sulphuric acid, which was derived from the oxidation of pyrite, and possibly some organic acids dissolved the small disseminated particles of zinc and iron carbonates and sulphides and carried them in solution to places where the water found an easy escape upward, as in the shattered and faulted zones near Friedensville. Several hundred and perhaps several thousand feet of limestone and shales overlay the present exposed strata while this work of concentration was most active, and consequently the waters were of considerably higher temperature and had greater soluble power than those of the present time. The marcasite found with the pyrite indicates, however, that the ore-bearing solutions precipitated their load under moderate temperatures.

The pyrite and sphalerite were deposited in part in the fissures through which the solutions passed and in part metasomatic replacement of the limestone. At the intersections of fissures through which solutions were passing the mingling of waters of somewhat different composition caused increased precipitation and resulted in the formation of the great masses of ore already described. Metasomatic replacement of the dolomitic limestones seems to have been much more common than precipitation of ore in existing fissures. The dense black finely crystalline masses of sphalerite preserve the texture of the original limestone. In some places the contact between the ore and the limestone is sharp and regular, but in most places it is otherwise, probably owing to the lack of homogeneity of the greater part of the limestone, which permitted the solutions to migrate different distances from the trunk channels.

The Friedensville ore deposits represent the segregation of zinc minerals that were obtained from a great thickness of limestones. The limestones in the vicinity of the mines are probably 2,500 to 3,000 feet thick, and perhaps as great a thickness has been removed by erosion. The probability is that the ore was collected throughout a thickness of limestones aggregating 5,000 to 6,000 feet. This thickness is approximately twice that of the limestone formations of the region, but owing to the intense folding to which they were subjected the vertical thickness in the Saucon Valley was probably doubled.

The process of segregation was undoubtedly slow, but it has extended from the end of the Ordovician period, when the first great orogenic movements folded and faulted the limestones of the region, up to the present time. The segregation of pyrite by meteoric waters is probably still taking place in the region, and no doubt disseminated zinc minerals are likewise being dissolved near the surface,

carried downward to great depths, and deposited from ascending waters. Thus the formation of the deposits represents a time interval of millions of years.

The deposits as originally formed consisted almost entirely of pyrite, marcasite, and sphalerite. Calamine, smithsonite, limonite, greenockite, and much of the quartz, calcite, and dolomite are all secondary and are the products of alteration by surficial waters. Water charged with silica converted part of the sphalerite into calamine, while carbonic acid changed other portions into smithsonite. In all probability part of the sulphide ore was oxidized to the sulphate and removed in solution, though the richness of the calamine and smithsonite veins seems to indicate that little of the zinc was removed. Parts of the pyrite and marcasite was converted into ocherous limonite, but the greater part seems to have been converted into ferrous sulphate and carried away in solution. Some of this sulphate may have been reprecipitated as pyrite or marcasite at lower levels, but evidence of this reaction is lacking.

No indication of the sulphide enrichment of the zinc ore was shown, and it is doubtful whether the sphalerite ore has been appreciably enriched. If it was not the sulphide ore should maintain approximately the same tenor to the lowest depths of profitable mining. In few regions is the sulphide enrichment of zinc ores of much consequence, and the Friedensville deposits seem to be no exception. Some secondary sphalerite in the form of small honey-yellow crystals that line the walls of small cavities in the limestones can be frequently found, but it is of little economic importance. Crystals of quartz, calcite, and dolomite occur in a similar manner. As to the paragenesis of the minerals, pseudomorphs of smithsonite after dolomite, and quartz crystals that are coated with smithsonite containing cadmium show the later formation of the zinc carbonate.

Near the surface most of the sulphide ore was changed, although some veins that were probably more compact and less permeable were altered to a depth of only a few feet. In the Ueberroth mine large masses of calamine at the greatest depths worked, about 225 feet, show an unusual depth of alteration. There is a strong probability that some of the more permeable veins will yield oxidized ore at considerably greater depths.

As any vein is followed down the blende makes its appearance at the side of the vein whereas the calamine and smithsonite occupy a continually narrowing portion of the center of the vein, thus showing that the downward-percolating waters found an easier passage through the middle of the vein than at either side. The presence of sulphide and oxidized ores at the same level was a serious inconvenience on account of the necessity for mining the two kinds of ore separately and it is said that much sulphide ore which might have

been removed at small cost was left in the mine. For the reasons already mentioned and also because the spelter made from the oxidized ores was superior to that made from the sulphide ore the failure to remove all the blende was not considered much of a loss.

Mining.

As the oxidized ore lay at the surface in a mixture of residual clay and limestone boulders, it was natural to begin mining by the open-pit method. At the Ueberroth mine, where the ore was first discovered, about 100,000 tons of ore was removed in this way. On the exhaustion of the large surface pocket the ore was followed downward along the numerous crevices in the limestone, which were filled with loose oxidized ore. On account of the falling of large masses of limestone open-pit mining was finally abandoned. Shafts were then sunk, and the ore was hoisted. At the Ueberroth and Old Hartman mines inclined slopes were run for the working of the deeper-lying ore bodies to the southwest, and from them levels were opened along the veins.

The instability of the inclosing limestone strata required much timbering to hold the rock in place, and many shafts and drifts were destroyed by the settling of great masses of rock. At the Ueberroth mine several shafts had to be abandoned for this reason.

In sinking the shafts and slopes and in driving the drifts it was necessary to remove some of the limestone. Some of this material was hoisted and thrown on the dump, but a considerable portion was taken back into the mine to fill old stopes and to underpin loose rock.

Almost at the beginning of mining the water problem became serious. The shattered and cavernous character of the limestones of the Saucon Valley permits easy passage for the underground waters, so that the waters from practically the entire upper part of the valley readily found their way into the mines as the workings were deepened sufficiently to produce a gradient requisite for flow.

At the depth of 46 feet the flow of water was very strong, and at the depth of 150 feet it became necessary to install what was at that time the largest pumping engine in the world. This engine, called "the President," was started January 29, 1872, and was run continuously until October 28, 1876, and for a few short periods later. This one engine had a calculated pumping capacity of 12,000 gallons a minute from a depth of 300 feet, although it rarely if ever reached that figure. Most of the time it pumped less than 9,000 gallons a minute. It was never necessary to run all the pumps at their full capacity in order to keep the works free of water. Some published figures that give the amount of water pumped are greatly exaggerated.

The great amount of water pumped from the mines has suggested a remote source for some of the water, but calculations show that after allowing for 40 per cent evaporation of the average rainfall of the entire drainage basin of Saucon Creek the amount of water pumped from the mines formed only about one-third of the remaining water falling in the valley. Hence there seems to be no reason to doubt that all the mine waters were of local meteoric origin.

When the big engine was running and pumping the water from the Ueberroth mine at a depth of 225 feet, practically all the wells and springs in the Saucon Valley went dry, and lawsuits against the company were threatened. Wells were drained as far to the southwest as Limeport, a distance of 4½ miles, and about 3½ miles to the east. For a time the city of Philadelphia considered a plan to run a pipe line from the mines to Philadelphia as an additional source of water supply.

At one time the water of Saucon Creek, at a point about 1¼ miles southwest of the mine, entirely disappeared through an easy passageway into the mine. By means of refuse thrown into the creek bed the opening was sealed. When the large engine was stopped in 1876 the creek below the mine shrank to a small part of its former volume, and it regained its normal size only after the mine had filled with water. In 1868 the pumping cost was said to be $6 to the ton of ore, and in 1876, when the Ueberroth mine was closed, the pumping cost was said to be $4 to the ton of ore, the greatest item in the entire cost of mining. The high cost was due to the fact that only one shift was worked, and altogether the daily output was only 55 to 60 tons. For the same cost of pumping a much greater output could have been made.

On account of the different treatment required by the oxidized ores (calamine and smithsonite) and the sulphide ores (sphalerite associated with pyrite) and the difficulty of separating them if they should become mixed, the mining of the different kinds of ores was carried on separately so far as possible. In places some sulphide ore was left in the mines, even though it could have been easily removed. An additional reason for the failure to remove all the sulphide ore was the fact that these ores had to be roasted to remove a large portion of the sulphur before they were sent to the furnaces, and the companies were in danger of being enjoined by the courts if the sulphur fumes at Friedensville or South Bethlehem should become obnoxious. It is possible that if the mines are reopened the sulphur gases may be economically utilized in the manufacture of sulphuric acid. The greatest drawback to the profitable production of sulphuric acid will undoubtedly be the large amount of limestone necessarily mined with the ore. Sulphuric acid was made at Bergen Point, N. J., from the sulphide ore from the Correll mine. For a time the proj-

ect was profitable, but the increasing amount of limestone in the ore finally caused the company to abandon the attempt to utilize the sulphur.

Milling.

Both the oxidized and the sulphide ores as they came from the mine were mixed with impurities and had to be concentrated before being sent to the furnaces. In the calamine and smithsonite the impurities were mainly clay and small pieces of limestone and a few fragments of pyrite and sphalerite, whereas in the sphalerite ore the chief gangue material was limestone. For these reasons the two kinds of ore required different treatment.

As the oxidized ores were brought from the mine the larger masses were broken by sledges, and the richer fragments that happened to be fairly free from impurities were picked out by hand and sent directly to the spelter works. The small fragments mixed with clay were passed through log washers or cone washers. From the washers the ore was discharged on grizzlies or revolving screens and then thrown on picking tables, where boys removed pieces of limestone, pyrite, and sphalerite. The greater portion of the concentrate obtained from the washers went to the oxide furnaces.

The water from the washers, which carried the clay and small bits of ore and rock, was drained into settling ponds. Later much of the coarser material that had been deposited near the inlet to these pits was dug and worked in buddles or tossing tubs, and considerable fine calamine and smithsonite were thus recovered. A four-compartment Hartz jig with an eccentric stroke was tried on these sands but was not successful. In a few places the tailings were found to contain more zinc than the heads. The failure was due to many thin flat pieces of calamine that had a tendency to go with the tailings. The concentrate recovered from the sands was sent to the oxide works. The average zinc content of the dried oxidized concentrate as sent to the furnaces was about 20 per cent.

The intimate mixture of the sphalerite ore and the limestone rendered concentration difficult. A gradation from pure sphalerite into pure limestone could be seen in some specimens of ore as brought from the mine. From such material a clean product could be obtained only after extremely fine grinding. The result was that during the period of most active operations the richer ore was picked by hand and sent to the roasting furnaces or roasting heaps and the remainder thrown aside.

After 1876 sizing and jigging of the sulphide ores was tried. Hand jigs were first used, and these were later replaced by Hartz jigs having several compartments. They were not entirely satisfactory, as the tailings were invariably high in zinc.

The best of the sulphide ore was roasted in reverberatory furnaces for spelter. The lower grade ore was often heap roasted and sent to the oxide furnaces or reroasted in the reverberatory furnaces and sent to the spelter works.

The best of the hand-picked sphalerite ore contained from 42 to 44 per cent zinc; the remainder contained from 15 to 25 per cent.

Outlook for future development.

The belief is general that the Friedensville mines were closed on account of the exhaustion of the ore. This belief, however, is incorrect, as the ore bodies were as large in the lowest workings as near the surface; the veins give no evidence of dying out as the depth increases and the sulphide ores show little change in tenor. How much ore remains is purely a matter of conjecture, but there is every reason to believe that the mines can still furnish a large tonnage of sulphide ore as well as considerable calamine and smithsonite ore. The property owned by the Friedensville Zinc Co. in Saucon Valley is shown on Plate IV.

Another frequently reported cause for closing the mines was the threatened litigation of the farmers whose wells were drained by the pumping that was required to keep the mines free of water. This explanation is likewise without foundation, as the courts have repeatedly upheld the principle that no mining company is liable for damages incurred by the withdrawal of water from previous users so long as this withdrawal is necessary in order to remove the ore and the water is neither sold nor disposed of in such a manner as to damage other property.

The chief reason why the principal operating company, the Lehigh Zinc Co., closed its mines, which consisted of the Ueberroth, Old Hartman, and Three Cornered Lot mines, in 1876, was its inability to compete with the New Jersey Zinc Co. in the manufacture of zinc oxide made from the zinc ores of Sterling Hill and Franklin Furnace, N. J., or with the companies operating in the Central States in the production of spelter. The Lehigh Zinc Co. owned the Wetherill patents for the manufacture of zinc oxide and had previously prevented the New Jersey Zinc Co. from producing zinc oxide from the New Jersey ores in an expensive suit brought for infringement of patent. The Wetherill patents having expired in 1876, the New Jersey Zinc Co. was about to enter the field with new oxide furnaces. As it was costing the Lehigh Zinc Co. from $4 to $6 for each ton of ore raised merely to pump the water from the mines, whereas the ore at Sterling Hill could be loaded on the cars at a cost not exceeding 75 cents a ton,[54] it was foreseen that competition would be ruinous to the Lehigh Zinc Co. An agreement was therefore made by which the Lehigh Zinc Co.

[54]Eng. and Min. Jour., vol. 22, p. 216, 1876.

closed its mines and contracted with the New Jersey Zinc Co. for 1,000 tons of ore a month from the New Jersey mines for a period of five years.

Clerc[55], who was familiar with the operations of the Friedensville mines at that time, says:

The causes which led to the extinction of the Lehigh Zinc Co. and the abandonment of the two first named mines Ueberroth and Old Hartman were briefly these: The impossibility of competing successfully in the oxide market with the owners of the big mine in Sussex County, N. J., after the expiration of the patents covering the oxide process left them free to take the trade, or in the sheet zinc and metal market with the western smelters using cheaper and richer ores, at a time when a general depression of all manufacturing enterprises made it unusually burdensome to carry the heavy bonded indebtedness incurred during a period of high prices and general inflation in acquiring mines and putting up machinery to work them. Under more favorable circumstances it is probable that these mines could have been profitably worked for years to come; for although the pumping expenses were heavy, they were not excessive, considered as a royalty on the ore, and these charges per ton would diminish in proportion to the amount of ore mined.

The present owners have not announced their intentions regarding these mines, but should the borings that are now being made show favorable results it is hoped that the mines may be reopened shortly and again become active producers.

Zinc Mines.

Ueberroth mine.—The Ueberroth mine was the largest and most profitable of all the Friedensville mines. It was worked continuously from 1853 to 1876 and for short periods in 1886 and 1891 and produced about 300,000 tons of calamine and smithsonite ore. In no other mine in the region did the oxidized ore continue to such depths. To a depth of 150 feet the oxidized ores were found between loose blocks of limestone, some of enormous size. At that depth, however, the limestone became solid and the ore veins, which were 12 to 40 feet in width, had well-defined walls. The limestone strata and the main ore beds which lie between them are practically vertical in the Ueberroth mine and strike N. 80° E.

There were two very rich veins in this mine known as the Stadiger and Trotter, both of which were worked continuously for a distance of about 1,000 feet along the strike. Another productive ore body was known as the Blende vein. This vein was not worked so extensively on account of the larger amount of sulphide ore which it contained. At the deepest level worked this vein was very well-developed and yielded ore that ran about 30 per cent zinc. One-third of the ore was rich enough to be sent directly to the smelters; the remaining two-thirds, however, required concentration.

Clerc[56] gives the following description of this mine:

The ore came close to the surface, and a very rich pocket was found in the clay above and around limestone boulders, which is estimated to have produced 100,000 tons of ore. When this body of ore was exhausted the ore was followed down in crevices between the boulders. These crevices lie in planes parallel to the bedding of the limestone, or in planes perpendicular to it, and preserve great regularity in their position and a parallel course for several hundred yards in a northeast and southwest direction; they are nearly vertical, and at the depth of 225 feet, to which the mine was worked, showed no signs of closing up. The ores at first were exclusively calamine and smithsonite, but at greater depth blende made its appearance, coating the walls of the crevices and in some cases penetrating into them several feet; in other cases segregated as rich seams, which nearly filled the cross openings. At first it was confined to the northeastern end of the mine, but at the lowest depth reached it could be traced almost continuously to the extreme southwestern end. The dip of the ore body appeared to be regular and to the southwest. Six of these parallel crevices were worked and about as many crossings, and where they intersected rich bunches of ore were found, some of which were as much as 60 feet across and 20 feet thick. All the indications seemed to point with increasing certainty to the existence of a backbone or underlying deposit of

[55] Clerc, F. L., U. S. Geol. Survey Mineral Resources, 1882, p. 365, 1883.

[56] Clerc, F. L., U. S. Geol. Survey Mineral Resources, 1882, pp. 362-363, 1883.

blende, out of the reach of the action of meteoric waters, from the continuation of which the oxidized ores have been derived. Timbering the mine was always a serious difficulty, but the greatest obstacle to be overcome was the water. Even at a depth of 46 feet the flow was already very strong; at the depth of 150 feet it was found necessary to put in what was then the largest pumping engine in the world. This engine, which is a single cylinder, double acting, condensing, walking-beam engine, with a pair of flywheels, has a 110-inch cylinder and a 10-foot stroke and is calculated to work four 30-inch plunger pumps and four 30-inch lift pumps, with 10-foot stroke, and to take water from a depth of 300 feet. At the time it was stopped it was running from six to seven strokes a minute, and was working three pairs of 30-inch pumps and one pair of 22-inch pumps, and was easily handling all the water that came to them. The pump shaft and foundation for the engine were no less remarkable in their way. The latter was built up from the solid rock, 60 feet below the surface of the ground of hewn blocks of Potsdam sandstone; the former, which measured 30 feet by 20 feet in the clear, was started on a small crevice and timbered with 12-inch square yellow pine sticks and divided into three compartments and further strengthened by two open brattices of the same timber. When the pitch of the vein carried it out of the shaft the rest of the depth was sunk through solid rock.

Several shafts were sunk at this mine, but these have been destroyed by caving. At present the old open pit, which is approximately circular and measures about 480 feet in diameter, is filled with water the level of which lies less than 30 feet from the surface. Nearly all the buildings which were formerly near the mine have been completely razed; the pumping-engine house and office, the only ones remaining, are in ruins. (See Pl. V).

Old Hartman mine.—About a quarter of a mile southwest of the Ueberroth mine is the Old Hartman mine, which now consists of two open pits about 400 by 250 feet in extent, both nearly filled with water. Like the Ueberroth, the Old Hartman mine was first worked exclusively for calamine and smithsonite, but large bodies of blende were found nearer the surface than in the Ueberroth mine. The oxidized ores were worked to the depth of 150 feet, although much sulphide ore was found nearer the surface. The last work done in this mine was the driving of a slope to work a fine vein of sphalerite ore.

The limestones of the Old Hartman mine show much brecciation (See Pl. VI, B, p. 104) but are less cavernous than those in the Ueberroth mine. The water problem here was less serious than in the Ueberroth mine and the mine was operated for a year after the large engine at the Ueberroth pit was stopped. Had grouting been employed the necessary pumping might have been considerably reduced. At the present time the water level in the two openings is somewhat lower than in the Ueberroth pit.

The Old Hartman mine was worked both by open cut and by shafts sunk in the limestones. The vein system is similar to that of the Ueberroth mine, although no veins were followed for so great a distance. The veins of the two mines seem to be entirely distinct. The veins worked are shown on the map (Pl. IV).

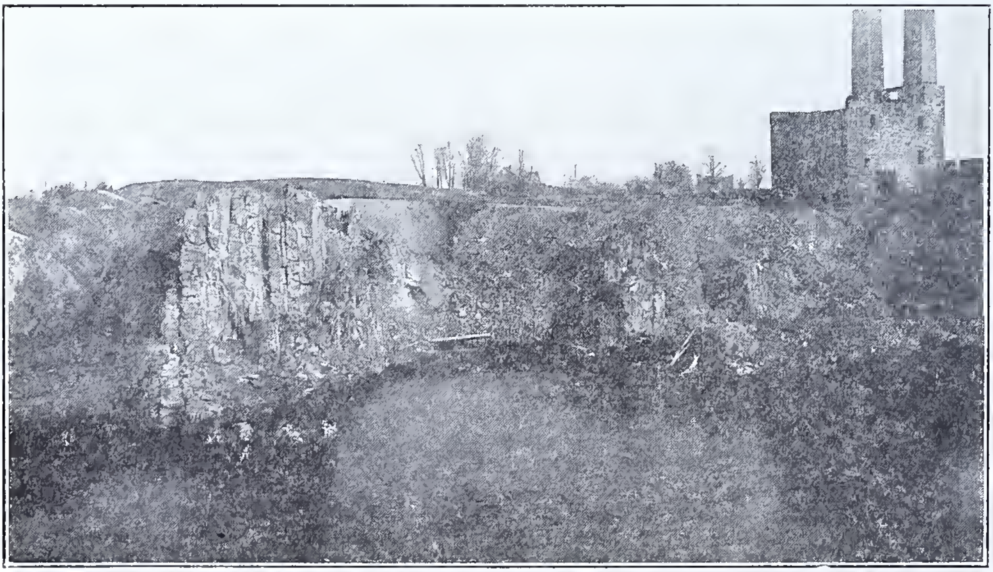
Correll mine.—The Correll or Saucon mine is about one-eighth mile southeast of the Old Hartman mine. It was actively worked as early as 1859 and much of the time between that date and 1881, but since that time it has furnished little ore. The mine produced less oxidized ore in proportion to the sulphide ore than did the Ueberroth mine. It was worked by open cut until 1876, after which underground mining predominated, and when work ceased its depth was 200 feet. The limestone strata and the principal ore veins which lie between them dip to the south at angles that range from 30° to 40°. The limestones are regular and show few effects of disturbance or of solution.

In 1876 a 12-foot vein of sulphide ore was being worked. At greater depth this width increased to 40 feet and in one place to 50 feet. The whole length of working in the Correll mine was about 700 feet along the strike. The veins were worked to the western limits of the property of the Correll estate and are continued in the New Hartman mine.

The open pit of the Correll mine, which is now partly filled with water, measures approximately 200 by 300 feet.

New Hartman mine.—The Hartman mine, which adjoins the Correll property on the west, is the only mine in the region that was exclusively worked by underground methods. The ore was struck in a vertical shaft at a depth of 110 feet and continued downward to a depth of 200 feet. Very little oxidized ore was found. When work ceased the principal ore vein was said to be 50 feet wide. Its strike was almost due east, and the dip was 35° S.

A. Ueberroth mine, Friedensville, while in operation, about 1877.



B. Recent view of Ueberroth mine.

Three-Cornered Lot mine.—This mine is located east of the Friedensville-Colesville road, about 700 feet northeast of the Friedensville Church. The open cut, which is partly filled with water, is irregular in shape and has an average diameter of about 250 feet. Here, as in most of the mines, open-cut mining finally gave place to underground mining, and several veins were followed under the road and beneath the property that lies west of the road north of the church. The veins undoubtedly belong to the same system as those of the Correll and New Hartman mines and have the same general strike and dip. The exposed limestone strata dip on the average 35° S. and strike N. 85° E.

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COPPER.

Throughout the eastern United States the rocks of Triassic age in many places contain traces of copper. Many of these Trassic copper deposits have been worked, particularly in colonial times, but very few operations have been successful. In the Allentown quadrangle copper minerals occur in two places, and both localities have been prospected. One of the deposits is 1 mile south of Leithsville and the other about the same distance southeast of Leithsville. A few years ago they were investigated by James Fisher, of Bethlehem, who dug several trenches and shallow shafts but did not succeed in discovering any ore that was commercially valuable.

In both localities the minerals, associated rocks, and manner of occurrence are similar. The ore-bearing rock is a conglomerate that is loosely cemented with red to gray clay or shale. The pebbles have a maximum size of 4 inches, are well rounded, and consist of quartzite, limestones, and shales. The copper is in the form of malachite and occurs as a thin coating that surrounds the quartzite and limestone pebbles. It has in part replaced some of the cementing material that was formerly present but in the main has been formed by precipitation in the pore spaces of the conglomerate. In some specimens the coating of malachite about the pebbles is a quarter of an inch thick, but usually it is thinner.

As the copper-bearing rock has never been thoroughly sampled the value of the ore can not be determined. In picked specimens the copper content is 4 or 5 per cent, but the strata thus far exposed that carry the malachite average only a fraction of 1 per cent copper, which is entirely too low to be of any economic value. The malachite is irregularly distributed throughout the conglomerate and is not confined to any definite horizon or series of beds—a condition that would be a serious inconvenience in the development of the property. The extent of the copper-bearing rocks is not known, as the region is covered with vegetation and hillside wash.

Although there can be no disagreement regarding the value of the deposit thus far exposed, an unfounded belief exists that deeper development would reveal valuable ore. The existence of valuable ore is, however, highly improbable, although the character of the ore would unquestionably change with depth. The malachite would give place to sulphide minerals, either chalcocite or chalcopyrite, but the tenor would not necessarily be changed.

The origin of the copper in the rocks is believed to have been entirely independent of any relation with igneous rocks. The nearest point at which the Triassic diabase, the only igneous rocks in the region of more recent date than the conglomerates that carry the copper, comes to the surface is about 3 miles south of the deposit. The only way in which the diabase could have contributed to the deposition of the copper would have been by the intrusion of other dikes in the vicinity of the deposit which never reached the surface. Hot ascending waters, stimulated by the proximity of the mass of heated rock, could have carried the copper from these dikes into the conglomerates in the form of sulphides, which later changed under atmospheric action into the basic carbonate that is now present.

The deposits have probably originated in the way that so many other copper deposits in red sandstones in different parts of the world are supposed to have been formed. The inclosing rocks were deposited rapidly under arid conditions, following a long period of rock decay, and possibly some copper sulphide minerals from the pre-Cambrian crystalline rocks near by were swept into the same basin. When later percolating waters that contained salt or gypsum in solution passed through these beds the copper was segregated by solution and reprecipitation, probably in the form of chalcocite. The later alteration to malachite has been effected by the action of downward-moving waters charged with oxygen and carbon dioxide.

MANGANESE.

Throughout the region there is abundant evidence of the presence of manganese in the form of dendritic markings of manganese oxide along the joint cracks of decayed rocks, especially in the areas of gneiss. Under such conditions local segregations of manganese oxide should be found. However, as the hydrous oxides of iron and manganese are dissolved and precipitated in the same manner, the manganese oxide, the less abundant of the two, is seldom found distinct from the iron oxide. Almost all the limonite iron ores of the region contain some manganese, and in some mines the ore averages from 1 to 3 per cent of manganese. Such ores have always been in demand for the production of basic iron. In general, the limonite ores of the

Cambrian quartzites, which are found along the slopes of the mountains and which are termed mountain ores, contain the highest percentage of manganese. The manganese-bearing material is in most of the ore a mixture of pyrolusite and psilomelane, although specimens of each separately are sometimes found.

Where the manganese is associated with limonite it can seldom be recognized except by the darker color of the ore. Where limonite geodes occur there is a tendency for the manganese oxide to be present in largest amounts in the inner layers, which commonly show botryoidal surfaces and fibrous structure.

In certain limonite mines layers of ore high enough in their manganese content to be called manganese ores have been found. Several mines in the region, especially those along the north side of the mountain northeast of Emaus, have shipped small quantities of this ore, but it was always incidental to the mining of the iron ore. In the Wharton mine of the Thomas Iron Co., about 1½ miles southeast of Hellertown, the iron ore averaged more than 2 per cent of manganese and here and there specimens of nearly pure manganese oxide were found. One of these specimens, which showed beautiful dendritic structure yielded the following results when analyzed in the laboratory of the Thomas Iron Co.:

Analysis of manganese ore from Wharton mine.

Fe	0.868
SiO_2	.46
P	.046
Mn	52.72

The manganese content of the limonite ores found in the limestone regions is apt to be lower than in those just described, yet in some mines high-grade manganese ores have been found. In the Ironton mines, which are in the limestone region a short distance west of Coplay and hence outside the borders of the Allentown quadrangle, though they are similar to the mines of this area, two layers of high-grade manganese ore were found. They yielded several hundred tons of ore. Three different specimens were analyzed, as follows:

Analyses of manganese ores from Ironton, Lehigh County, Pa.

	1	2	3
Mn	52.631	56.58	17.648
Fe	2.562	----------	26.400
P	.063	trace	.095
S	trace	----------	.010

Sample 1 analyzed by A. S. McCreath, 2 by Henry Pemberton, and 3 by David McCreath.

Although manganese is widespread throughout the region in association with the limonite ores there is no probability that any deposit is rich enough in manganese to be developed independently of the iron ores. In the Allentown quadrangle manganese ore must

be regarded as a by-product in the working of the limonite iron mines.

An interesting occurrence of manganese was observed in May, 1924 in an excavation for a building adjoining the Lehigh University campus on the north slope of South Mountain about 320 feet above sea level. The exposure revealed 5 to 10 feet of glacial till overlying a water-deposited fine glacial sand 4 to 16 feet thick. The till was composed of rounded and angular rocks, ranging in size up to 3½ feet in diameter and enclosed in a stiff clay matrix. The sand was well sorted, and strained brownish yellow by ferruginous matter. A layer of clay was said to underlie the sand but was not exposed. Within the sand, in irregular patches or in occasional bands, and commonly at the contact of the sand and overlying till, concentration of manganese dioxide and some ferric oxide had cemented the sands into a manganiferous sandstone. In some places the pyrolusite, seemingly with little or no limonite, was surrounded by a thin band in which the limonite was present with little or no pyrolusite. The pyrolusite penetrates a large glacial conglomerate boulder in the base of the till to a depth of about one-half inch where the till is in contact with the sand. At the contact of the sand and till a few specimens of almost pure pyrolusite with marked botryoidal structure were observed where the crystallization of the mineral from solution had pushed aside the clay. No positive replacement of the sand by either the pyrolusite or the limonite was noted, although there may well have been some action of this kind.

Although the deposit is of no economic importance it is of interest because of its recent formation and its origion. It is post-glacial in age as the till and sand were both formed during the Ice Age. The sand was laid down in a lake (Lake Packer) that existed in the region when the ice in its advance dammed the Lehigh River until the waters flowed westward into the Schuylkill. Later the ice deposited the till on the sand.

The source of the manganese was undoubtedly the pyroxenes and amphiboles of the gneisses that form the mountains. As these minerals were decomposed the manganese and iron present in them passed into solution and were carried down the hill into the sand stratum. Here the downward movement of the solutions was stopped by clay, or for some reason the manganese and iron were precipitated from the stagnant solution in the form of pyrolusite and limonite.

This occurrence shows plainly the way in which manganese deposits are forming and gives reason for believing that small deposits of workable grade may be found in some sections of this immediate region or elsewhere in the southeastern part of the State.

GOLD.

Gold is discussed in this report merely to call attention to its absence in this region in profitable quantities and to warn credulous persons to avoid the expenditure of time and money in its search. Reports are current that gold has been found in many places in the southern half of the quadrangle, and considerable money has been spent in the sinking of shafts mostly in the regions of gneiss. It seems that in some places small particles of pyrite or chalcopyrite in the rocks have been mistaken for gold and that in other places operators of the divining rod have been the means of exciting false hopes of hidden wealth. Some unscrupulous or incompetent assayers have reported high gold assays in rocks that were shown later to be absolutely barren.

Within recent years two shafts, 150 and 180 feet in depth, were sunk in the Triassic conglomerate about 1½ miles southwest of Limeport in search of gold. It is reported that a vein of free-milling gold ore was found which contained about $30 in gold and $15 in silver to the ton but that the vein was soon exhausted. These statements, which seem to be questionable, have not been verified. The deposit was later worked for a time under lease by four men, who installed a system of sluicing, but the project was a failure. When visited some time after operations had ceased the only metallic substances observed in the rock on the dump were a few small particles of pyrite and chalcopyrite in the cementing material of the conglomerate.

About 12 years ago a shaft 103 feet in depth was sunk in gneiss about 1 mile southeast of Mountainville. The materials about the opening indicate that pegmatite carrying much coarse hornblende and some quartz, magnetite, pyrite, and feldspar was found. It was claimed that some valuable rare minerals were obtained, but careful examination has failed to detect their presence.

Gold is also said to have been found in the Backenstoe graphite mine, 1 mile east of Vera Cruz station. This mine is described below (p. 160).

Though very accurate assays of some of the pyrite so common in the rocks of the region may show traces of gold, it is extremely improbable that gold in paying quantities occurs in the rocks of the Allentown quadrangle.

CEMENT.

The most valuable mineral product of the Allentown quadrangle at present is the cement rock, which extends in a narrow band from Coplay to Nazareth. The decline of the iron-mining industry in this section began just about the time the cement industry started, and at present the manufacure of cement is of greater importance than

all the other industries based on the mineral products of the region combined. The cement district of the Allentown quadrangle forms a part of the "Lehigh district," which has been gradually extended in both directions until now it includes cement plants in Berks, Lehigh, and Northampton counties, Pa., and Warren County, N. J. Ten companies are operating in the quadrangle, eight of which obtain practically all their rock within its borders. With few exceptions for many years the annual output of each company has shown an increase over that of the preceding year.

Historical Sketch.

As in other regions the manufacture of natural hydraulic cement preceded that of Portland cement. In New York the construction of the Erie Canal in 1818-19 led to the discovery of natural hydraulic cement, and in this region the digging of the canal of the Lehigh Coal & Navigation Co. accomplished the same result. Rock suitable for hydraulic cement was found just above Lehigh Gap, where Palmerton is now, and also at Siegfried's Bridge (now Siegfried). The rock at Lehigh Gap seemed to be preferable, and a cement mill was built there under the direction of the company's engineers. This plant operated by Samuel Glace from 1826 to 1830 and furnished material for many of the canal locks. When the best cement rock near Lehigh Gap was exhausted for a time material was quarried about 6 miles east of the gap and hauled to the plant. However, in 1830 it was decided to abandon the mill and to erect a new one at Siegfried's Bridge, where suitable rock was known to be obtainable. In a small pamphlet by William H. Glace, entitled "A narrative of hydraulic cement mined in the Lehigh Valley," the following description is given.

Capt. Theodore H. Howell, residing at Siegfrieds, informed me that when he came there in 1837 there were four kilns erected and in operation. They were known as draw kilns, fire being placed in the eye at the bottom of the kilns, drawn at the bottom and hoisted up an incline plane or tramway and emptied into a hopper, where the stones were crushed by machinery shaped like a corn crusher, then dropped down and ground by burr millstones, then placed in boxes or trays with handles, then transported in scows to points on canal where needed. The scows were drawn by mules with a steersman on a platform on the rear of the scow, having a large tiller, 15 feet long, ending in a large blade or paddle, which tiller was fastened on a socket at the balance point, and thus lifted with little exertion at will, and when in use was a powerful means to turn the boat in any direction wanted. At that time the capacity of this plant was ten barrels per day.

The canal, from the place down to the Allentown dam, was through a farming community, and the loam and clay on the banks of the canal were vulnerable places for the muskrats, which were plentiful. They seemed to be busy constantly and would in a short time make a hole in the embankment, which if not attended to would empty the canal and stop transportation.

The method to remedy this was an alarm given by the bank watchman, the scow or cement boat sent for, which with the mules trotting, a man in front blowing a horn, giving them the right of way, the steersman on his platform at the rear, meanwhile the workingmen were emptying the trays (which had been covered with a tarpaulin), on the bottom of the boat, mixing it with gravel and sand,dipping up

water from the canal and making the concrete. As soon as the leak was reached a small coffer dam was built around it, water emptied and the concrete applied, stamped with wooden stampers in the break, the frame work removed as soon as grouting hardened. In those years Samuel Glace was supervisor of the canal from Slate Dam to Allentown Dam, in addition to the cement work at Siegfrieds until 1841.

Natural hydraulic cement continued to be manufactured in the region, as shown by the following quotation.[57]

On the eastern side of the river, directly opposite the village [Whitehall, now Cementon], are the extensive Hydraulic Cement Works of E. Eckert & Co. These works have been in successful operation for a number of years, and the cement (which is mined in the neighborhood) is said to be equal in every respect to the celebrated Rosendale cement.

As early as 1867 David O. Saylor, who was at the head of the Coplay Cement Co., a natural hydraulic cement company at Coplay, began experimentation to try to improve the quality of the cement produced. In the preceding year Portland cement was brought to this country from England, where it had been manufactured since 1825 and this fact seemed to act as a stimulus to cement manufacturers in this country. By selecting the stone carefully Saylor finally succeeded about 1872 in making Portland cement, which was exhibited at the Centennial Exposition, where it received a "certificate of award."

The Coplay Cement Co. (now the Coplay Cement Manufacturing Co.) continued to make Portland cement, steadily improving its quality, and other plants were soon started in the same vicinity. For some years many difficulties were encountered and meanwhile the importations of Portland cement from England were gradually increasing. In time, however, the Portland cement of the Lehigh district acquired the reputation, which it still holds, of being the equal of any other Portland cement made, and cement importation practically ceased. The situation in 1878 is described by Prime[58] in his report of the geology of Lehigh and Northampton counties.

Two companies, as mentioned in Report DD, have tried to utilize the hydraulic properties of this limestone in Northampton County, but neither of them have done much of anything in the last four or five years, and every time the quarries have been visited by members of the present geological survey they have been found standing unworked. These companies are "The Old Lehigh Cement Works" and "The Allen Cement Company."

It must not be supposed because these companies have been apparently unsuccessful that there is no future in the business of manufacturing hydraulic cement in this part of the State; on the contrary the success of the Coplay Cement Co. shows what perseverance under difficulties can and does accomplish. Of course the composition of some of the cement-stone beds is far more favorable to the manufacture of cement than that of others, but all may be more or less profitably utilized for careful intermixture. There is no reason why the manufacture of hydraulic and Portland cements should not be slowly and surely extended, not only rendering this portion of the State free from foreign competitors, but actually rivaling these in many of the western markets on account of the excellence of the product and the cheapness of freights.

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[57] Henry, M. S., History of the Lehigh Valley, p. 302, 1860.
[58] Pennsylvania Second Geol. Survey, Rept. D3, vol. 1, pp. 164-165, 1883.

For many years both natural and Portland cements were made in the district, in some places even by the same company, but at present little natural cement is produced. Only a few years ago a natural cement company whose works were at Egypt, a few miles west of the borders of the Allentown quadrangle, ceased operations and dismantled its kilns.

For a while the Lehigh district enjoyed a monopoly in the manufacture of Portland cement, until it was discovered that an equally good product could be made from many different materials. Lehigh cement was shipped all over the country, and much of it was exported. Though no other cement region occupies so favorable a position with reference to accessibility to good cement rock and fuel and proximity to great industrial centers, yet on account of freight charges the market for the cement of the Lehigh district becomes smaller year by year, owing to the erection of cement plants in other sections of the country. Fortunately, however, the demand for Portland cement has kept pace with the growth of cement manufacturing plants, so that this district continues to prosper regardless of increasing competition. The following table shows the prominent position which the Lehigh district holds.

Portland cement produced in the Lehigh district and in the United States, 1890-1922, in barrels.[1]

Year	Output of Lehigh district	Total output of United States	Percentage of total output manufactured in Lehigh district	Year	Output of Lehigh district	Total output of United States	Percentage of total output manufactured in Lehigh district
1890	201,000	335,500	60.0	1907	24,417,686	48,785,390	50.0
1891	248,500	454,813	54.7	1908	20,200,387	51,072,612	39.6
1892	280,840	547,440	51.3	1909	24,246,706	64,991,431	37.3
1893	265,317	590,652	44.9	1910	26,315,359	76,549,951	34.4
1894	485,329	798,757	60.8	1911	25,972,108	78,528,637	33.1
1895	634,276	990,324	64.0	1912	24,762,083	82,438,096	30.0
1896	1,048,154	1,543,023	68.1	1913	27,139,601	92,097,131	29.5
1897	2,002,059	2,677,775	74.8	1914	24,614,933	88,230,170	27.9
1898	2,674,304	3,692,284	72.4	1915	24,876,442	85,914,907	29.0
1899	4,110,132	5,652,266	72.7	1916	24,105,381	91,521,198	26.3
1900	6,153,629	8,482,020	72.6	1917	24,423,507	92,814,202	26.3
1901	8,595,340	12,711,225	67.7	1918	19,701,870	71,081,663	27.7
1902	10,829,922	17,230,644	62.8	1919	22,747,956	80,777,935	28.3
1903	12,324,922	22,342,973	55.2	1920	25,417,804	100,023,245	25.4
1904	14,211,039	26,505,881	53.7	1921	25,571,726[2]	98,842,049	25.9
1905	17,368,687	35,246,812	49.3	1922	31,195,617[2]	114,789,984	27.2
1906	22,784,613	46,463,424	49.0	1923	35,721,751[2]	137,460,238	25.9

[1]U. S. Geol. Survey Mineral Resources.
[2]Includes Eastern Pennsylvania, New Jersey and Maryland.

In this region there have been many improvements since the first successful manufacture of Portland cement. For a time the run of quarry was used, with the result that some companies which owned quarries in which the rock had practically the composition now looked upon as most desirable were able to produce a better product than other companies with less suitable rock. Also but few companies

were able to produce a uniform product on account of the variation in composition of the rock, even in the same quarry. Now, however, the chemist of each company sees that the proper mixtures are used, and the physical tests also serve as a check, so that the old hit or miss method has given place to exact scientific processes and the variations in the product are very slight.

The changes in processes of manufacture have been equally great, and each year mechanical modifications are introduced which tend to increase the output and to lower the cost of production. Even now these improvements are being made so rapidly throughout the district that detailed descriptions of the mills might be out of date before they were published. The greatest improvements have been in the character of kilns by which the old upright kiln has given place to the modern rotary kiln that is now universally used throughout the region.

Cement Materials.

The Allentown quadrangle is well supplied with the necessary raw materials for the manufacture of Portland cement. These materials consist of a black argillaceous limestone, known as cement rock, and a low-magnesium, relatively pure limestone, known as cement limestone. The underlying limestones, of Beekmantown age, which are in most places too high in magnesia for use in Portland cement, locally contain beds that are serviceable. In a few plants it is necessary at times to add some clay or slate, either of which can be readily procured close at hand. Some other companies require a small amount of high calcium limestone which must be brought from other regions.

The cement rock and cement limestone are of Ordovician age and in most places in the quadrangle can easily be distinguished. The basal cement limestone consists of good limestone with some interbedded shaly limestone strata toward the top; the upper cement rock consists mainly of thin-bedded argillaceous limestones that locally contain beds of pure limestone. On the accompanying map a line is drawn between these two limestones, yet it should be recognized that the division in some places is drawn somewhat arbitrarily, especially near Lehigh River.

Cement Rock.

Distribution.—The black argillaceous limestone, or cement rock, extends across the quadrangle in a continuous band from Nazareth to Siegfried. From Siegfried to Howertown the band is approximately 1½ miles in width, but it narrows northeastward to less than one-eighth of a mile in the vicinity of Bath. Thence eastward it maintains a width of approximately three-quarters of a mile, except

at Nazareth, where it widens to 1 mile. The widening and narrowing of the band are due partly to differences in thickness but mainly to the variation in structure of the strata in different places.

In most places in the quadrangle the northern boundary of the cement rock is accurately indicated by an abrupt change in topography, as the line of contact lies at the base of the steep slopes which mark the southern margin of the slate belt. This change in slope is due to the relative ease with which the cement rock is removed by weathering, mainly by solution, in comparison with the slate, which is much less soluble.

In several places the southern boundary of the cement rock belt is also marked by a change in slope. The underlying cement limestone, which is more soluble than the cement rock, produces a more nearly level topography, and the change from one belt to the other is marked by a change in slope. The map (Pl. II) in several places shows this contact line at the foot of a pronounced slope.

The cement-rock belt continues beyond the borders of the quadrangle but with less continuity. In the adjoining Slatington quadrangle the belt is interrupted by faults or by areas where the limestone was never deposited.

Character.—The cement rock is an argillaceous limestone that is intermediate both in composition and in stratigraphic position between pure limestone and shale or slate. In color it suggests the overlying Ordovician slates, and in many places it shows marked slaty cleavage. A freshly broken piece is bluish black and shows glistening particles of sericite that are too fine to be individually distinguishable except as light is reflected by them. The unaltered rock breaks partly along cleavage planes and partly along bedding planes, producing hackly or in some specimens conchoidal surfaces that are unlike those of either the pure limestones beneath or the slates above. As the rock weathers, however, it separates into small cleavage fragments so similar to those that result from the decomposition and disintegration of slate that it is difficult to distinguish between soil derived from slate and that derived from cement rock. Both soils are filled with thin fragments of light yellowish-gray rock the largest of which are 1 inch in length.

In almost every quarry the rock shows the effect of great compression, by which it has been shattered, thus permitting water carrying mineral matter in solution to precipitate quartz and calcite in the open fissures and irregular cavities. (See Pl. VI, A). In some places the vein matter is pure-white calcite, in other places white granular quartz, but more commonly it is a mixture of the two. The

A. Cement rock in quarry of Bath Portland Cement Co., showing crumpling and numerous veins of calcite and quartz.

B. Limestone breccia in Old Hartman mine, Friedensville.

white veins in contrast with the black rock are very prominent in the working faces of most quarries. There is a rough parallelism of the veins, which tend to follow bedding planes, although they break across the beds in many places. Adjoining the veins smooth slickensided surfaces that are coated with a soft black carbonaceous substance resembling graphite are very common.

Small cubes of pyrite are frequently noticed near the veins and locally in the rock where the vein material is absent. Purple and green fluorite have also been found in the vein material in a few localities.

Chemical composition.—The chemical composition of the cement rock changes from bed to bed or even in the same bed within a single quarry opening. In some quarries the average rock contains almost exactly the right proportions of the materials required for the best grade of Portland cement. Several plants in the district for months at a time do not find it necessary to add either pure limestone or clay. In most quarries the rock varies in different parts so that tracks must be run to several places and the requisite mixture obtained by the proper combination of the different kinds of rock. In other quarries, however, the average rock runs too low in calcium carbonate, so that some high-grade limestone must invariably be added. Some of the plants are fortunate enough to have quarries in the underlying cement limestone, but others must bring limestone from a distance. Much limestone from Annville, Lebanon County, Pa., is used in the district. In a few quarries the average rock runs too high in calcium carbonate, so that some other material must at times be added. For this purpose the local residual limestone and glacial clays are utilized.

With few exceptions the basal beds of cement rock are higher in lime than the upper strata. Accordingly a plant whose quarry is located near the northern margin of the belt and which works the upper beds will need to add high-grade limestone to the cement rock, whereas a plant which has a quarry near the southern margin of the belt and which works the basal beds may need to add some clay at times. The Penn Allen and Dexter companies show this relation very well, for the Penn Allen Co. finds it necessary to add limestones brought from other points and the Dexter Co. occasionally must add some clay.

In general the cement rock toward the western part of the quadrangle runs too low in calcium carbonate, and the plants located there must buy limestone. The average rock in the central and eastern parts of the belt has almost the desired composition for Portland cement, but some of it requires a small admixture of clay, as noted in the descriptions of the individual plants.

The change in composition of the cement rock in depth is well shown in the following series of analyses of rock from a 350-foot boring made by the Atlas Portland Cement Co. in its quarry at Northampton. The last 40 feet penetrated was evidently the cement limestone, which lies beneath the cement rock, and the other specimens that are high in lime came from layers of pure limestone which are interbedded with the argillaceous limestone (cement rock).

Analyses of cement rock in 350-foot boring in quarry of Atlas Portland Cement Co., Northampton, Pa.

Date received	Depth	SiO_2	$Fe_2O_3 + Al_2O_3$	$CaCO_3$	$MgCO_3$	Total
1908	Feet					
	0– 5			64.61		
	5– 10			65.54		
	10– 15			63.85		
	15– 20			65.29		
	20– 25			63.00		
	25– 30			62.07		
	30– 35			62.09		
	35– 40			61.17		
	40– 45			61.23		
	45– 50			64.01		
June 23	Average of first 50 feet	21.72	7.88	63.27	5.33	98.20
1908	Feet					
	50– 55			63.57		
	55– 60			64.91		
	60– 65			56.55		
	65– 70			50.52		
	70– 75			67.92		
	75– 80			69.26		
	80– 85			69.19		
	85– 90			69.19		
	90– 95			67.09		
	95–100			66.25		
June 23	Average of 50 to 100 feet	21.42	8.26	64.42	4.45	98.55
	100–105			68.04		
	105–110			67.62		
	110–115			65.62		
	115–120			66.64		
	120–125			67.10		
	125–130			64.80		
	130–135			66.59		
	135–140			72.12		
	140–145			65.69		
	145–150			63.49		
June 24	Average of 100 to 150 feet	19.36	7.90	66.80	4.33	98.39
	150–155			66.16		
	155–160			64.97		
	160–165			66.51		
	165–170			64.63		
	170–175			65.91		
	175–180			69.45		
	180–185			69.10		
	185–190			68.93		
	190–195			65.15		
	195–200			69.28		
June 24	Average of 150 to 200 feet	17.22	8.02	67.44	4.95	97.63

Analyses of cement rock in 350-foot boring in quarry of Atlas Portland Cement Co., Northampton, Pa.—Continued.

Date received	Depth	SiO_2	$Fe_2O_3+Al_2O_3$	$CaCO_3$	$MgCO_3$	Total
	200–205			71.35		
	205–210			63.44		
	210–215			61.72		
	215–220			61.21		
	220–225			68.77		
	225–230			74.70		
	230–235			76.85		
	235–240			77.54		
	240–245			78.40		
	245–250			77.71		
June 24	Average of 200 to 250 feet	16.28	7.00	71.18	4.85	99.31
	250–255			74.32		
	255–260			71.39		
	260–265			78.10		
	265–270			79.99		
	270–275			76.80		
	275–280			71.65		
	280–285			74.58		
	285–290			75.02		
	290–295			73.11		
	295–300			72.69		
June 29	Average of 250 to 300 feet	13.24	7.32	74.78	4.18	99.52
1908	Feet					
	300–305			72.24		
	305–310			74.79		
	310–315			81.41		
	315–320			85.82		
	320–325			78.92		
	325–330			79.26		
	330–335			78.40		
	335–340			78.40		
	340–345			78.15		
	345–350			78.06		
July 20	Average of 300–350 feet	11.08	5.88	78.53	3.58	99.07

Analyses of cement rock from Allentown quadrangle, Pa.

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	16.29	16.28	11.86	14.78	13.28	11.10	18.15	15.12	12.40	11.19	16.40	14.54
$Fe_2O_3+Al_2O_3$	7.52	8.67	6.86	7.00	6.68	5.66	8.82	7.56	5.50	6.52	7.30	7.82
$CaCO_3$	72.15	69.64	74.86	71.37	74.30	77.60	68.14	71.42	75.78	75.80	66.18	72.67
$MgCO_3$	4.35	4.64	4.64	4.45	4.20	4.17	3.88	4.68	4.78	5.32	7.32	3.89

1. Bonneville quarry, Lawrence Portland Cement Co.
2. Quarry No. 3, east of Hokendauqua Creek, Lawrence Portland Cement Co.
3. Quarry No. 3, near Howertown, Atlas Portland Cement Co.
4. Quarry of Bath Portland Cement Co., Portland.
5. Quarry of Bath Portland Cement Co.
6. Quarry of Dexter Portland Cement Co.
7. Quarry of Dexter Portland Cement Co.
8. Quarry of Phoenix Portland Cement Co.
9. Quarry of Phoenix Portland Cemeut Co.
10. Quarry of Nazareth Cement Co.
11. Quarry of Nazareth Cement Co.
12. Quarry of Penn Allen Cement Co.

These analyses should not be regarded as necessarily characteristic of the particular quarries where the samples were taken but are fairly typical of the average cement rock of the district. It

would no doubt be possible to obtain similar series of analyses from a single quarry. In the records of the cement companies there are a few analyses in which the calcium carbonate is less than 60 per cent and others in which it exceeds 85 per cent, but these are not typical.

In addition to the substances given in the above analyses small quantities of TiO_2, FeO, MnO, P_2O_5, SrO, CaS, K_2O, and Na_2O have been found in the cement rock of the region. The effect of these upon the quality of the cement is problematic. Ullmann and Boyer[59] give a series of determinations of TiO_2 in specimens of cement rock from this region. They range from 0.14 to 0.24 per cent.

Meade[60] gives a complete analysis, made by himself, of a sample of cement rock from the quarry of the Dexter Portland Cement Co. that has practically the correct composition for burning. It is as follows:

Complete analysis of cement rock from quarry of Dexter Portland Cement Co.

SiO_2	13.44	K_2O	.72
TiO_2	0.23	P_2O_5	.22
Al_2O_3	4.55	S	.33
Fe_2O_3	.56	C	.75
FeO	.88	CO_2	32.94
MnO	.06	H_2O above 105°C.	1.55
CaO	41.84		
MgO	1.94		100.32
Na_2O	.31		

Fossils.—The writer has made careful search for fossils in the cement rock of the region but has found only a single specimen in the typical black argillaceous limestone. This specimen is a fairly well preserved graptolite and was found in the old quarry of the Coplay Cement Manufacturing Co. The carbonaceous matter in the rock, which gives it a dark color, may perhaps have been derived from the remains of graptolites that disintegrated during the metamorphism of the rock.

The layers of crystalline limestone that are locally interbedded with the true cement rock contain abundant fossils, most of which, however, are fragmentary. They can scarcely be recognized except on weathered surfaces. At the large quarry of the Atlas Portland Cement Co. and also the one near Howertown many crinoid stems, bryozoa, and brachiopods have been found.

Structure.—In many quarries it is difficult to determine the bedding planes unless an interbedded pure limestone stratum can be found. Where the pure limestone beds are absent the quartz and calcite veins, which in general are present along the bedding planes, are useful in determining the structure. Almost invariably

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[59] Ullmann, H. M., and Boyer, J. W., The determination of titanium in argillaceous limestones (cement rock): Chem. Eng., vol. 10, pp. 163-165, 1909.
[60] Meade, R. K., Portland cement, 2d ed., p. 50, Easton Pa., 1911.

the cement-rock strata are greatly crumpled and yet have low angles of dip. The normal direction of dip is toward the northwest, beneath the Martinsburg slates which constitute the slate hills, but in many quarries some beds dip in other directions.

When the rocks of the region were subjected to the great dynamic forces that formed the Appalachian ridges the cement-rock strata were so weak that they yielded by minor folding and faulting, so that the different layers locally became thickened but were not tilted at high angles. The cement rock in very few places dips more than 45° and in most places much less, whereas in the adjoining limestone belt vertical or even overturned beds are not uncommon.

Thickness.—The crumpled character of the cement rock, the absence of any beds that are sufficiently distinct to be recognized in different openings, and the lack of any continuous or approximately continuous section across the belt render the exact determination of the thickness of the cement rock of the region impossible. The local thickening of the beds due to compression also needs to be taken into account in any estimates of thickness.

In the 350-foot boring of the Atlas Portland Cement Co. described above (p. 106) the upper 310 feet seems to be cement rock and the last 40 feet to be the underlying cement limestone. The rocks here, although somewhat crumpled, were so nearly flat that 300 feet of cement strata can be safely assumed. As the boring was in the bottom of the quarry, below somewhat more than 100 feet of cement rock, the total thickness in that place must be about 400 feet, which is believed to be the maximum thickness within the quadrangle. From Weaversville to Nazareth the thickness scarcely exceeds 200 feet, and in the vicinity of Bath it may be less.

The decided difference in the thickness of the cement rock in different places may be due in part to local thickening as the rock yielded under the compression that resulted from widespread dynamic disturbances at the close of the Ordovician and Carboniferous periods, but it is due mainly to the deposition of a greater thickness of muddy calcareous beds in the region of Lehigh River than farther east.

Relations.—The cement rock rests conformably upon the underlying cement limestone. In some places the basal beds of the cement rock seem to dovetail into the upper beds of the underlying purer limestone, as in the quarries of the Pennsylvania Cement Co. east of Bath.

The cement rock is conformably overlain by the shales and slates of the Martinsburg formation.

In many places in the quadrangle glacial clays that contain many cobbles and boulders overlie the cement rock. In some places this

overlying debris, which must be removed before the rock is blasted down, is as much as 15 feet in thickness and fills old pockets of solution in the ancient land surface, although the average thickness of this cover is probably less than 5 feet.

Cement Limestone.

Distribution.—A series of limestone strata high in calcium carbonate and low in magnesium carbonate extends across the quadrangle in a narrow band which has a width of an eighth to a quarter of a mile except southeast of Nazareth, where it widens to three-quarters of a mile. The area occupied by these strata adjoins on the south the area occupied by cement rock that has just been described. These beds are so easily accessible to the cement plants that they have been extensively quarried by the cement companies and are therefore called cement limestones. The Bath, Pennsylvania, Dexter, and Phoenix cement companies have quarries in this belt from which they obtain rock to mix with the cement rock when needed. The Nazareth Cement Co. has opened its quarry on the contact of the two kinds of rocks, so that the cement limestone occupies the southern part of the quarry and the cement rock the northern part.

A small area of cement limestone also lies about half a mile northwest of Lanark in the Saucon Valley, where it has been faulted down and hence preserved from erosion, which has removed all the cement rock that at one time occupied the intervening space between this region and the continuous band about 9 miles to the northwest.

Character.—The typical cement limestone of the region is a light to dark gray, coarsely crystalline limestone, which when broken shows many lustrous cleavage surfaces of dark calcite. Less common are beds of fine-grained, dark-colored limestone which differs but little in appearance from the underlying dolomitic limestone.

The beds are massive as a rule and in many places show numerous joint planes, some of which are greatly enlarged by solution. These joint planes are commonly filled with residual or glacial clay. One quarry which was otherwise good was abandoned on account of the numerous clay seams or pockets, and in several places they have considerably increased the cost of quarrying because the clay had to be removed before the rock could be blasted.

Chemical composition.—Normally the cement limestone runs high in calcium carbonate and low in magnesium carbonate but like the cement rock differs greatly in composition from place to place. The analyses given below are typical of the rock. In some quarries much of the rock on analysis shows from 90 to 95 per cent calcium carbonate. Also some quarries contain a few beds that contain as much as 12 per cent magnesium carbonate, which is so high that this rock must be sorted out and discarded.

Analyses of cement limestones.

	1	2	3	4
SiO_2	4.68	7.03	11.90	5.82
$Al_2O_3 + Fe_2O_3$	1.88	2.60	3.06	2.96
$CaCO_3$	89.95	87.03	77.50	86.20
$MgCO_3$	3.17	2.54	6.90	4.64

1. Limestone quarry of Dexter Portland Cement Co.
2. South side of quarry of Nazareth Cement Co.
3. Quarry of Nazareth Cement Co. one-fourth mile south of Christian Springs Hotel.
4. Limestone quarry of Bath Portland Cement Co.

Fossils.—The cement limestones contain numerous fossil remains, most of which are fragmentary and scarcely determinable. Except on the weathered surfaces of the rocks they are not conspicuous. They are of the same character as those contained in the limestone layers that are interbedded with the argillaceous cement rock previously described (p. 103). Fragments of small crinoid stems are most abundant, but locally bryozoans are very common. The bryozoans belong to several different species, but the branching and headlike colonies are most abundant. Poorly preserved brachiopods are also occasionally found.

Structure.—The massive beds of the cement limestone have not crumpled like the thin beds of the cement rock, and steeply dipping and overturned folds are present. In the south side of the quarry of the Coplay Cement Manufacturing Co. on the west bank of Lehigh River at the extreme margin of the quadrangle there is an overturned synclinal fold. The syncline is overturned to the north, so that the cement limestone both overlies and underlies a mass of cement rock and all the beds dip to the southeast. In the quarry of the Nazareth Cement Co. the cement limestone strikes N. 55° W. and dips 42° NE.

Elsewhere in the region the cement limestone dips gently to the north or northwest at low angles and disappears beneath the cement rock.

Thickness.—The thickness of the cement limestone ranges from 100 to almost 200 feet. The greatest thickness is near Nazareth, where it can be determined with a fair degree of accuracy. At that place it is approximately 200 feet. In the vicinity of Bath it scarcely exceeds 100 feet, although the exact thickness can not be determined.

Relations—The cement limestone grades into the overlying argillaceous limestone or cement rock through an intermediate band of interbedded relatively pure limestone and impure argillaceous limestone. For this reason the two kinds of rocks, although lithologically dissimilar, are regarded as constituting a single geologic formation.

At the base the cement rock is in contact with the magnesian limestone. In this region the two formations are approximately conformable, although to the east, in New Jersey, there is a marked erosional unconformity between them in many places.

Glacial clay that contains included cobbles and boulders and that is of variable thickness rests upon the cement limestone in the belt shown on the map and interferes with the determination of the exact formation lines.

Other Materials for Making Cement.

Limestones.—Although most of the limestones that lie between the belt of cement limestones described above and the Cambrian sandstones and quartzites are prevailingly high in magnesia and hence unfit for Portland cement, there are a few beds in which the content of magnesium carbonate is well within the specified limits. These beds have been used in several places throughout the quadrangle.

Along the Central Railroad of New Jersey a quarter of a mile north of Catasauqua the Lawrence Portland Cement Co. operated a limestone quarry for many years. The material which was low in magnesium carbonate was shipped to the cement plant at Siegfried and that which contained too much magnesium for cement was sold to the Crane Iron Co. for flux. At times the company was able to use 75 per cent of the output for cement, but at other times scarcely 25 per cent. In most places the content of magnesium carbonate was fairly uniform in each bed of rock, but certain strata were suitable for cement in parts of the quarry but changed in composition sufficiently to be undesirable in other parts. Under the guidance of the chemist the quarrymen learned to detect the difference in appearance of the rocks low and high in magnesium carbonate, so that their separation was easy. Naturally steam shovels could not be used, as the different kinds of rock were thrown down together in blasting. The following analyses of samples taken at approximately equal distances from the northwest corner and going in turn along the north, east, and south faces were furnished by the Lawrence Portland Cement Co.

Analyses of limestones in quarry one-fourth mile north of Catasauqua.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	9.02	7.82	12.91	12.38	12.81	7.43	13.90	5.56	1.94	5.18	5.70
$Al_2O_3 + Fe_2O_3$	3.95	2.14	4.95	5.09	5.41	2.63	4.76	1.87	1.22	3.05	2.85
$CaCO_3$	82.12	85.50	79.65	79.03	75.50	85.32	76.94	87.23	92.57	88.30	85.63
$MgCO_3$	4.31	3.44	2.98	3.35	6.07	4.07	4.73	4.53	5.10	3.13	6.04

Along the Lehigh & New England Railroad a short distance north of Hanoverville the Lily White Cement Co. started to build a cement plant several years ago. Financial difficulties interfered with the completion of the buildings but the rock which the company proposed to use is now being quarried by the Industrial Limestone Co.

Some of the product is sold to the cement companies of the region. The Penn Allen Co. has bought large quantities of the rock to mix with its cement rock, which is deficient in calcium carbonate.

The quarry is opened at a point where a considerable thickness of high-grade limestones low in magnesium occur interbedded with dolomitic strata. Some of the beds are of such composition as to suggest the cement limestones and furnish excellent material for cement but in one part of the quarry the rock contains far too much magnesium for Portland cement and must be used for other purposes. The following analyses are furnished by the company:

Analyses of limestone from quarry of the Industrial Limestone Co.

	1	2	3
SiO_2	2.26	1.5	0.54
$Al_2O_3 + Fe_2O_3$	.74	.34	.28
$CaCO_3$	94.37	92.70	96.50
$MgCO_3$	2.24	4.15	1.76

Analysis 1 was made by the Penn Allen Portland Cement Co. and analyses 2 and 3 by F. F. Hintze, of Lehigh University.

A quarry was opened in the small area of pre-Cambrian crystalline limestones along the right bank of Monocacy Creek just west of Pine Top. The quarry was operated by the Monocacy Stone Co. but is now closed. Some of the rock was sold to the cement companies of the region, and doubtless the entire output could readily be disposed of in this way.

The rock is similar in character and of approximately the same age as the famous Franklin limestone of New Jersey that is so extensively quarried in the vicinity of Franklin Furnace and McAfee. The following analyses furnished by the Monocacy Stone Co. show the general character of the rock. Sample No. 1 was of medium grain and dark color; sample No. 2 was a coarsely crystalline white rock.

Analyses of crystalline limestone quarried by Monocacy Stone Co.

	1	2
$CaCO_3$	94.74	93.46
$MgCO_3$	1.96	1.75
Al_2O_3	.21	.69
SiO_2	2.08	2.78
Fe_2O_3	.37	.55
	99.36	99.23
CaO	53.11	52.39
MgO	.94	.84
Fe	.26	.39

Clay.—Some of the cement plants near Nazareth are compelled to use a small amount of clay with the cement rock to make the proper mixture for Portland cement. As a rule they use the local clay which overlies the cement rock and represents the residuum of insoluble materials left when the soluble portions of the rock were removed in solution. Some of it has been transported and

deposited by the waters from the melting of the ice sheet which once invaded the region. The glacial clays contain a few cobbles and boulders.

At one time the Nazareth Cement Co. operated a small clay pit near the mill, but in most places the thin deposit of clay that overlies the cement rock is more than sufficient for the needs of the plants. The Nazareth Cement Co. furnishes the following partial analyses of the local clays used:

Analyses of local clays used by Nazareth Cement Co. in manufacture of cement.

	1	2
SiO_2	63.10	70.10
$Al_2O_3 + Fe_2O_3$	20.62	20.04
CaO	.78	.30
MgO	2.70	1.25

Materials from Other Regions Used by Local Cement Companies.

Several companies operating in this region that are compelled to buy limestone to mix with their cement rock bring it from regions some distance beyond the borders of the quadrangle. The limestones quarried near Annville, Lebanon County, Pa., are used in several plants and some Franklin limestones from New Jersey is also shipped in. The Atlas Portland Cement Co. uses the Franklin limestone in the manufacture of white cement. To mix with it the company also ships in white clay, mostly from Saylorsburg, Monroe County, Pa. Most of the gypsum which is added to the clinker before grinding comes from western New York.

Analyses of Franklin limestone and limestone from Annville.

	1	2	3	4
$CaCO_3$	97.11	96.67	96.60	94.29
$MgCO_3$	1.12	1.34	3.54	3.14
SiO_2	.36	1.77	.46	2.13
Al_2O_3	.45		.36	
Fe_2O_3	.45		.36	

1. Limestone from Annville, R. K. Meade, analyst.
2. Average of 9 samples of limestone from Annville analyzed by Atlas Cement Co.
3. Franklin limestone, R. K. Meade, analyst.
4. Average of 19 samples of Franklin limestone analyzed by Atlas Portland Cement Co.

Cement Plants.

Atlas Portland Cement Co.—The Atlas Portland Cement Co. is the largest producer in the district. The company began operations on the west side of Lehigh River about 1 mile northwest of Coplay, where the Lehigh Hydraulic Cement Works were first operated in 1872. Later the company erected a mill on Hokendauqua Creek, where the Allen Cement Co. began manufacturing cement in 1872.

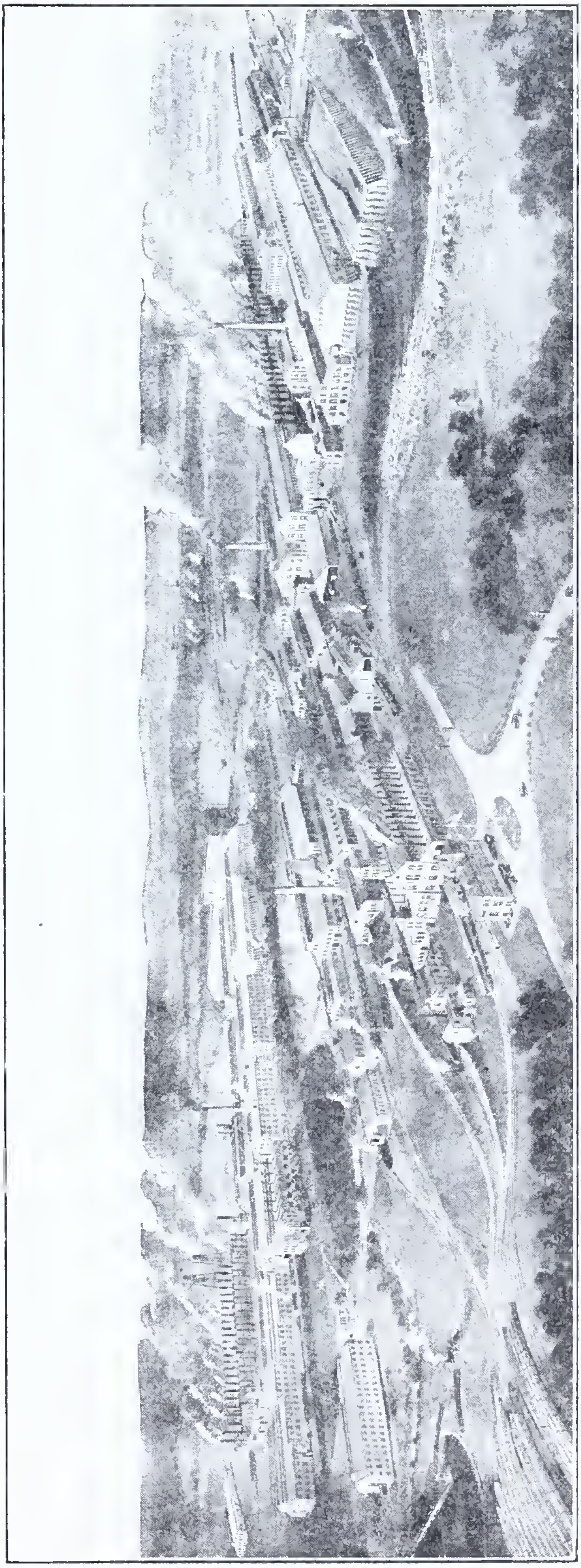

Plate VII. Plant of Atlas Portland Cement Co., Northampton, Pa.

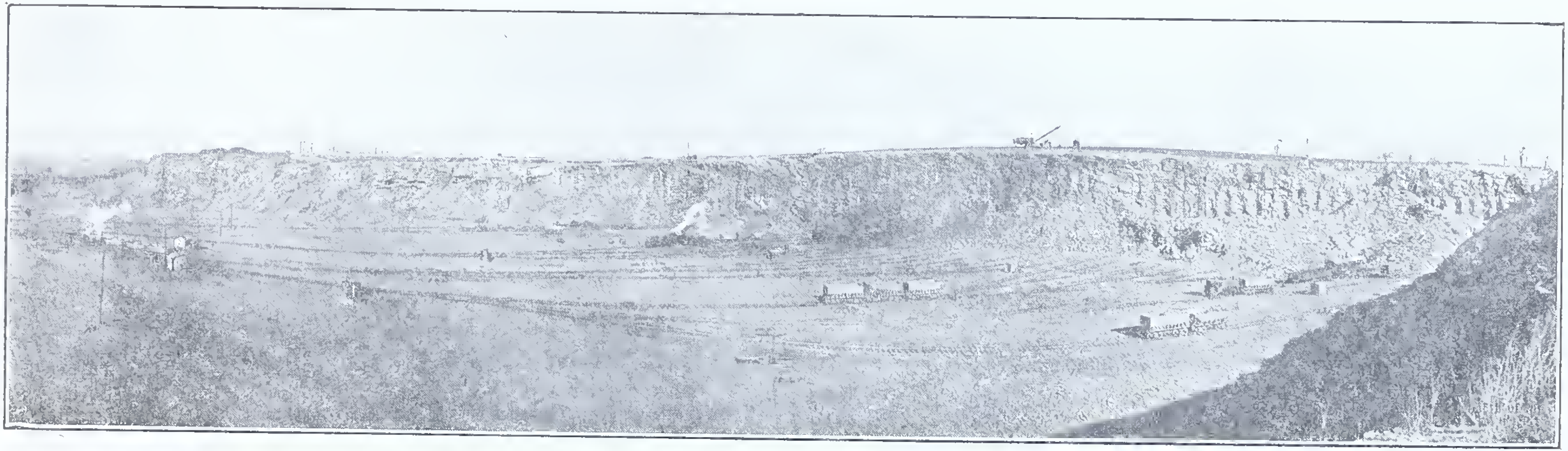

Plate VIII. Quarry of Atlas Portland Cement Co., Northampton, Pa.

The plant on the west side of the river has been idle for several years, but the plant along Hokendauqua Creek at Northampton has been enlarged until now it consists of 3 units each of which has a capacity of 10,000 barrels a day. If necessary each unit might produce as much as 12,000 barrels daily. This company furnished all the cement used in the construction of the locks and fortifications of the Panama Canal. The new mill, No. 4, has the largest rotary kiln used in the district. It is 220 feet long and 10 feet in diameter and has a capacity of 2,500 barrels a day The storage plant of the same mill has a capacity of 500,000 barrels.

The company has three large quarries on the east side of the river and one on the west side a short distance beyond the borders of the Allentown quadrangle. Quarry No. 1, the largest quarry in the district, extends for about 4,000 feet in a north-south direction and is approximately 2,000 feet wide. The working face for several years has been from 80 to 100 feet in height over most of the quarry, but at the beginning of operations it was considerably less. (See Pls. VII and VIII). The rock quarried here is an argillaceous limestone in gently folded beds overlain by a thin deposit of glacial clay of uneven thickness. The average rock in the quarry is too low in calcium so that limestone must be added.

Quarry No. 2, located southeast of Quarry No. 1, directly east of the office, is much smaller. It has not been used for several years on account of the numerous clay seams in the rock.

Quarry No. 3, near Howertown, is the quarry most recently opened. The strata dip on the average 17° NW. and strike N. 80° E. The quarry measures about 1,000 by 500 feet in area and has a working face of 80 feet. The rock in this quarry runs fairly high in calcium carbonate, much of it above 75 per cent, although the average is said to be approximately 72 per cent. Numerous limestone layers are interbedded with the cement rock, and these on weathered surfaces show many fossil remains of crinoid stems, Bryozoa, and brachiopods.

Bath Portland Cement Co.—The plant of the Bath Portland Cement Co. 1½ miles southwest of Bath has a daily capacity of 3,000 barrels of cement. (See Pl. IX). The buildings are almost on the contact of the cement rock and the cement limestone; and the cement limestone quarry is on one side and the cement rock quarry on the other. Sometimes for several months the material quarried in the cement-rock quarry is of such a composition that it can be used alone, but at other times it is necessary to add considerable limestone from the other quarry. By using the two quarries it is always possible to obtain the proper mixture for Portland cement. The amount of calcium carbonate in the cement rock ranges

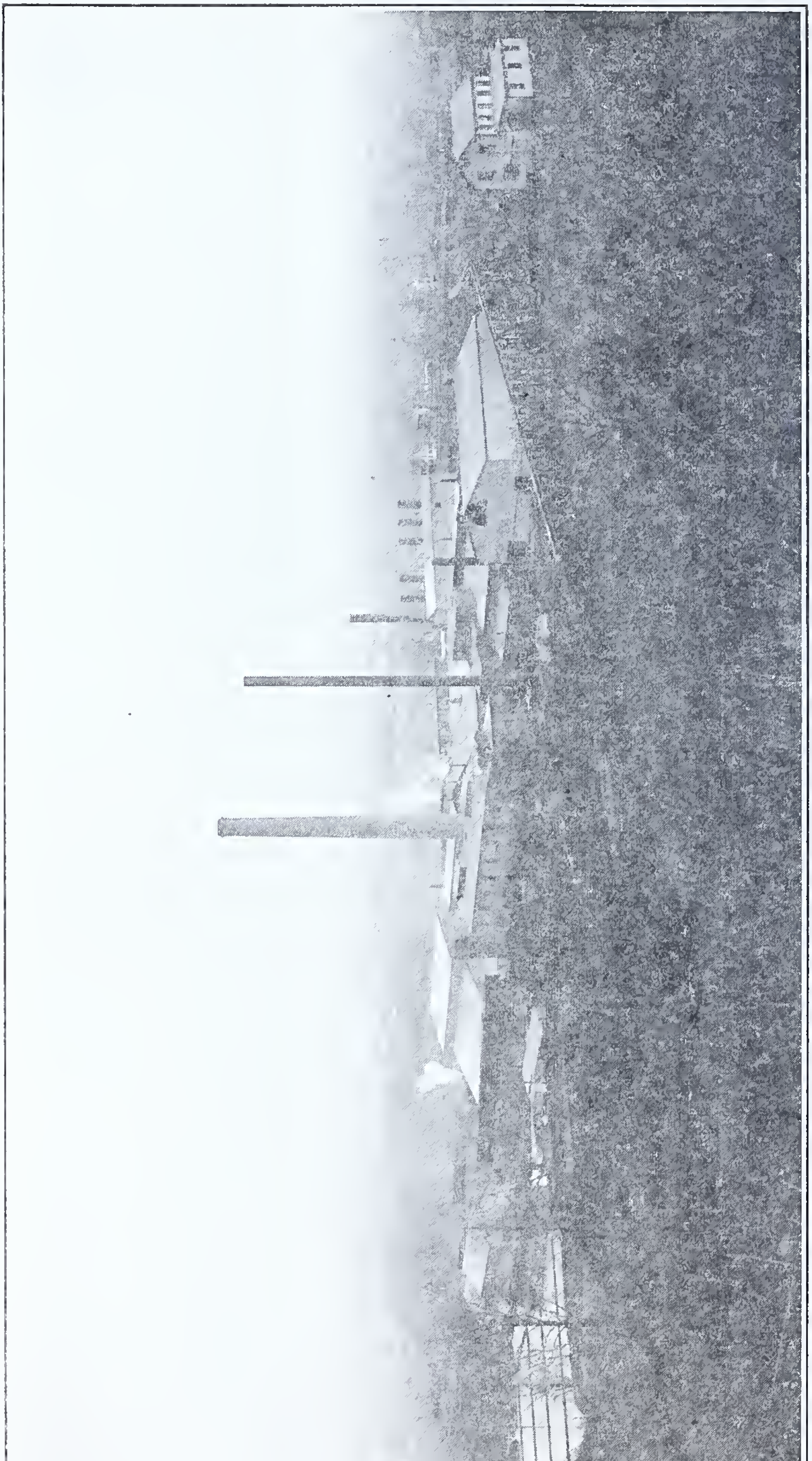

Plate IX. Plant of Bath Portland Cement Co., Bath, Pa.

from 69 to 77 per cent and in the limestone from 76 to 93 per cent. The amount of magnesium carbonate in the cement rock averages somewhat more than 4 per cent, and in the limestone it runs from 2 to 7 per cent.

The cement-rock quarry is about 450 by 400 feet in diameter and has a working face about 70 feet in height. The rock dips northwest at different angles in different parts of the quarry but the average dip is approximately 20°. The beds are greatly crumpled, especially in the south part of the quarry, where much calcite and quartz vein material is present.

In the limestone quarry which is about 400 by 200 feet in area and 55 feet in depth, the strata dip on the average 19° NW, and strike N. 33° E.

The water for the plant is obtained from several wells, that range from 200 to 250 feet in depth and furnish from 100 to 200 gallons a minute.

Coplay Cement Manufacturing Co.—The Coplay Cement Manufacturing Co. is the successor of the Coplay Cement Co. which produced the first Portland cement made in the district. The first mill and kilns were erected in the Allentown quadrangle a short distance above Coplay, but this mill is now abandoned, and the new mill and the quarries are in the adjoining Slatington quadrangle. This plant is of great historic interest. The manufacturing methods employed are of especial interest, as no other plant in the region exhibits so well the evolution of cement-making machinery and methods. The upright kilns, although now abandoned, are still in good condition. (See Pa. XI).

The old quarry, not in use, is partly in the Allentown but mainly in the Slatington quadrangle. A beautiful example of an overturned fold, which involved both the cement rock and the underlying cement limestone, is well shown in the south side of the quarry.

Dexter Portland Cement Co.—The plant and quarries of the Dexter Portland Cement Co. are 1 mile southwest of Nazareth. The main quarry of the company is in cement rock northwest of the mill, and there is a small limestone quarry on the south side of the buildings.

The rock of the main quarry in the upper part of the opening is slightly deficient in calcium carbonate, and where much of it is used a small amount of limestone must be added. Generally, however, the run of quarry has almost the correct composition for Portland cement, though within recent years it has frequently been necessary to add a small amount of surface clay. The rock dips

A. Loading cement rock at quarry face.

B. Remains of some of the first kilns used for the manufacture of Portland cement in the region, at Coplay, Pa.

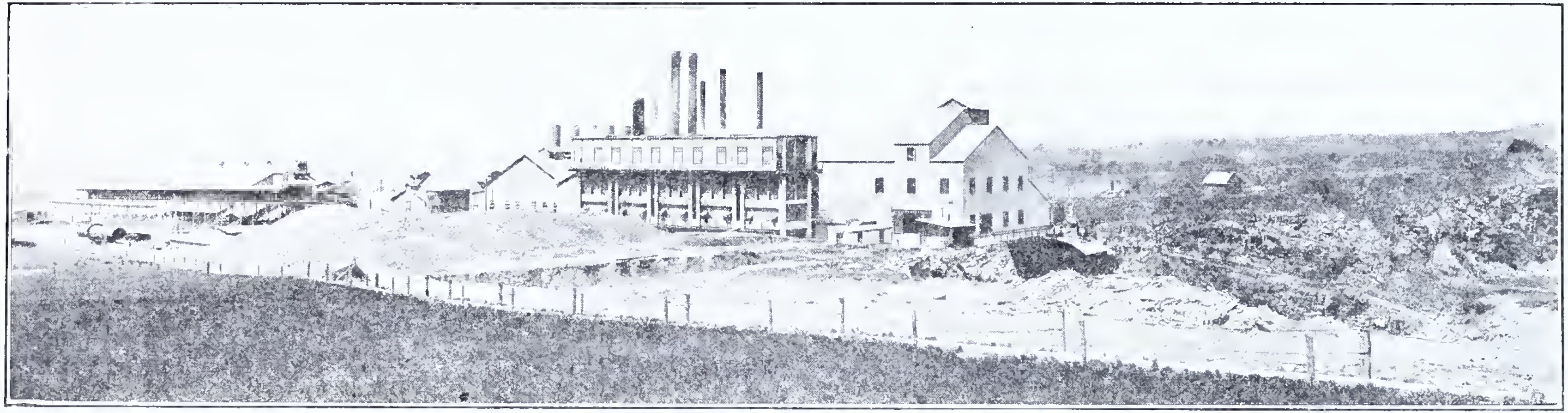

Plate XI. Plant of Dexter Portland Cement Co., Nazareth, Pa.

northeast at an angle of 7° to 18° and strikes N. 45°-60° W. The quarry has an approximate area of 600 by 900 feet and a working face of 100 feet. The rock is hauled from the quarry up an incline by cable to the mill.

The rock in the cement limestone quarry, which is seldom worked, is greatly shattered, so that the dip and strike can only be determined approximately. The dip is about 31° NE. and the strike N. 87° W. Numerous small fragments of crinoids can be seen on the weathered rock surfaces.

Hercules Portland Cement Co.—The mills of the Hercules Portland Cement Co. are a short distance beyond the boundaries of the Allentown quadrangle, about 2 miles northeast of Nazareth. The buildings were completed and the machinery was placed in position in 1907, but lack of capital prevented the company from starting operations. It has now been in operation several years. It was first known as the Atlantic Portland Cement Co. The plant consists of two units, each of which has a daily capacity of 7,500 barrels of cement.

The quarry of the company is in the cement limestone at the extreme edge of the quadrangle, part of the quarry lying to the north of the quadrangle. The contact between the cement limestone and the underlying dolomitic limestones is exposed in the quarry. Compression has caused the overlying thinner-bedded limestones to be thrown into folds whereas the underlying beds yielded by a slight faulting. Considerable quartz and calcite vein material occurs along the contact of the two formations. The cement limestone contains many fossil fragments and the underlying magnesian limestones have yielded numerous imperfect casts of gastropods.

Lawrence Portland Cement Co.—The plant of the Lawrence Portland Cement Co. is outside the quadrangle a short distance north of Siegfried and near the place where hydraulic limestone was first discovered in the region during the excavation for the canal of the Lehigh Coal & Navigation Co. The quarry, which long supplied the cement rock, is long, narrow, and deep and lies between the canal and the railroad. At present it is idle and filled with water. The company has a large quarry on the edge of the Allentown quadrangle, on Hokendauqua Creek. It was long worked by the Bonneville Portland Cement Co., a company no longer in existence. It is 400 by 150 feet in area and 135 feet deep and is the deepest cement quarry in the region. Some years ago the rock was tested by borings to depth of 275 feet. The percentage of calcium carbonate in the rock increased with depth, which is characteristic of most quarries of the region. From the surface to a depth of 220 feet the rock contained less than 70 per cent calcium

carbonate but more than 70 per cent below that depth. At the bottom the rock contained 73.28 per cent calcium carbonate. The strata are almost horizontal.

The east part of the quarry is on the alluvial plain of the creek. About 6 feet of alluvial pebbles, cobbles, and clay cover the cement rock.

This company is obliged to obtain limestone from other regions to mix with the cement rock. For many years they worked the quarry north of Catasauqua, which contained considerable rock low enough in magnesium carbonate to be used. Recently, however, the limestone from Annville has been mainly used.

Nazareth Cement Co.—The plant and quarry of the Nazareth Cement Co. are in the southeastern part of Nazareth. The company has a single large quarry, which has cement limestone in the southern part and the more argillaceous cement rock in the central and northern part. The line of separation between the two kinds of rock can be distinctly seen. The gray limestone at the base dips 42° NE. and strikes N. 55° W. The overlying cement rock is considerably crumpled and in places the structure can only be determined by the veins of calcite and quartz that have a tendency to follow the bedding planes. The quarry measures about 1200 by 400 feet in area and is about 50 feet deep. Usually the proper mixture can be obtained by quarrying both cement rock and cement limestone and mixing them in proper proportions. Some years ago, before the quarry had been extended so far to the north, a small clay pit was operated at times to obtain material to mix with the rock that ran too high in calcium carbonate.

Penn Allen Portland Cement Co.—The plant and quarry of the Penn Allen Portland Cement Co. are about 1¾ miles northeast of Bath. The company has but one quarry, in which the upper beds of cement rock are worked. As these strata are deficient in calcium carbonate limestone must be purchased. The company has used limestone quarried by the Industrial Limestone Co. near Hanoverville.

Pennsylvania Cement Co.—The works of the Pennsylvania Cement Co. are half a mile east of Bath. The southern part of the quarry is opened in the gray crystalline cement limestone and the northern part in the overlying black argillaceous cement rock. By combining the rock from the two portions in different proportions according to the kind of rock quarried in each a proper mixture for Portland cement is readily obtained. A few beds of high-magnesium limestone in the limestone quarry cause considerable difficulty. Pockets and seams of clay have been found in the quarry. The strata are considerably folded and in one place apparently faulted. In general they dip to the northwest at angles that range from 15° to 35°.

Phoenix Portland Cement Co.—The plant of the Phoenix Portland Cement Co. is half a mile southwest of Nazareth. The cement rock quarry is close to the mill, and the cement limestone quarry is 1 mile to the west, about half a mile north of Georgetown. The original quarry lay to the west of the plant but the present one is on the east side of the mill. The company formerly operated a quarry about a quarter of a mile to the north, close to the overlying slate. The rock was low in calcium carbonate and was used for natural cement. The rock in the main quarry dips 25° NW. and strikes N. 10° E. The plant has a daily capacity of 2,500 barrels.

Quarry Methods.

The quarry methods used by the cement companies are similar throughout the district. If possible the quarry is opened in the side of a hill and the tracks run into the quarry on the level so that as the quarry is extended a greater height of quarry face is obtained. In some places, however, it is necessary to open a quarry by excavating in a fairly level surface, and then the rock must be hauled up an incline to the surface.

In almost every quarry the variations in the rock in different parts make it advisable to have an extension face and tracks radiating to different points in order to obtain a mixture of uniform composition by combining the rock that is high in lime with that which is low in lime.

Formerly the rock was quarried in benches by the use of small drills and small blasts. Now, however, the companies have found it more economical to blow down enormous masses of rock at one time, at some blasts more than 60,000 tons. To do this a series of churn drill holes is put down about 10 to 15 feet back from the quarry face and about the same distance apart and driven to the level of the bottom of the quarry, which is usually about 100 feet. These holes are then charged with dynamite and exploded simultaneously, electric detonator being used. The rock is so easily shattered that these great blasts break most of the rock sufficiently to be loaded into cars. The larger blocks are broken by small charges of dynamite placed in holes made by small compressed-air hand drills.

Most of the companies use steam shovels for loading the rock into cars, although in some quarries the loading is done by hand. In the quarries that are driven into the hillsides on the level small locomotives or mules are used to haul the cars to the mill. Where the quarry is sunk below the level of the mill the cars are pushed by hand or hauled by mules to the foot of the incline, where they are attached to a cable to be hauled up the slope. The rock is dumped into a storage bin or directly into the gyratory crushers.

Methods of Portland Cement Manufacture.

In general there is little variation in the methods employed throughout the region for the manufacture of Portland cement, although somewhat different types of machinery are used. The different stages include (1) coarse grinding, (2) drying, (3) fine grinding, (4) calcining, (5) cooling or seasoning, (6) mixing with gypsum and grinding the clinker, and (7) seasoning in storage houses preparatory to bagging or packing in barrels. As these processes have been described in many publications that deal with the technical side of cement manufacture, they will be described briefly without mention of minor details or descriptions of all the types of machinery that are in the 10 plants of the quadrangle

1. The first stage of coarse grinding is done almost exclusively by great gyratory crushers. The properly combined rock is fed to the crushers from bins, dumped directly from the cars, or brought from the rock house by a belt conveyor. In some plants the rock passes to a set of smaller gyratory crushers or rolls.

2. The fragments of rocks are dried in short rotary kilns, which in a few plants are connected with the ends of the burning kilns and thus use the heated gases, which would otherwise escape at once into the air.

3. Different kinds of machines are used for the fine grinding—ball mills, tube mills, Huntington mills, Griffin mills, Kominuters, pulverizers, and other types. One mill used the Emerick air separator. Most of the mills grind the rock so that 95 per cent will pass through a 100-mesh screen and approximately 85 per cent will pass through a 200-mesh screen.

4. From the mills the pulverized rock is taken to bins and from there is fed into the kilns. At present all the companies use rotary kilns, which are continually being replaced by larger sizes. At first nearly all were about 40 feet in length, then 60, 80, and 100 feet, and one has recently been installed that is 220 feet in length and 10 feet in diameter. The fuel costs are considerably less in the larger kilns in proportion to the greatly increased capacity.

The kilns are fired with coal that is ground so fine that about 95 per cent will pass through a 100-mesh screen. The coal dust is forced into the kiln by fans or compressed air.

The first kilns used in the district were the upright. Several of these, known as Schoefer kilns, are still at the plant of the Coplay Cement Manufacturing Co. They consisted of three compartments, an upper heating chamber, a middle clinkering chamber, and a lower cooling chamber. The pulverized rock was mixed with water and molded into bricks, which were first dried and then carefully placed in the upper chamber by hand. The material passed in turn through

the other chambers and was withdrawn at the base. These kilns were not satisfactory, for much of the material was not uniformly burned, the amount of labor required was excessive, and scarcely more than 100 barrels of cement could be burned in each kiln daily. On the other hand, the fuel consumption in the upright kilns, which ranged from 45 to 65 pounds of coal to the barrel of cement, was much less than that required in the rotary kilns.

5. In some mills the clinker is stored under cover for a short time before being ground, but the practice of storing it in the open, where it is allowed to season for several weeks before grinding, is now being adopted by many mills.

6. After cooling and seasoning the clinker is taken to mills for regrinding. In almost every plant the same type of mill is used for grinding the clinker that is employed in pulverizing the rock. Before grinding gypsum is added to the clinker to retard the setting of the cement.

7. From the mills the cement is taken to the storage bins, where it remains for some time to season and is then withdrawn for shipment. It is shipped in paper or cloth bags that hold 95 pounds and occasionally in barrels that hold 380 pounds. The Bates valve bag is widely used in the district.

Economic Considerations.

The cement industry of the Lehigh district has undergone remarkable changes since it started. The factory price in bulk fell steadily from $3 a barrel in 1880 to 67.4 cents in 1912; it rose during the World War and reached $1.90 in 1920; then receded to $1 in 1923. The output with few exceptions has been increased from year to year, and yet the geographic market for the cement from this district has gradually decreased on account of the building of plants in sections of the country that were formerly supplied by the Lehigh product. In no other part of the country can cement be produced at so low a price as in this district, and the condition of the industry continues promising regardless of the competition and reduced prices. Increased efficiency has resulted, and the plants of the Lehigh district are models for other cement companies throughout the country. Experimentation still continues, and new types of machinery and new details in manufacturing are sure to result.

Some of the companies have failed to appreciate the value of a careful study of the structure of the cement-rock strata, by which their quarries could have been operated more economically. Likewise several of the plants might have been located more advantageously if the geology of the region had been carefully studied in advance.

The possession of cement rock of so nearly the correct composition for Portland cement, a very unusual occurrence, and the close proximity to the great industrial centers of the country are the two great assets that have enabled the Lehigh cement district to achieve and maintain its preeminent position. With the skill and efficiency acquired by years of experience and the increasing demand for cement the companies may look forward to many years of prosperity unless competition becomes too great.

BUILDING STONES.

In many places throughout the quadrangle buildings have been constructed of the local limestones, sandstones, and gneisses, but almost without exception these structures are old, most of them antedating the railroad. For many years no building stone has been quarried in the region other than for foundations. The Whitefield house in Nazareth, begun in 1740, probably the oldest house in the quadrangle, is built of local limestone.

Limestones. The abundant limestone strata that underlie most of the valleys of the quadrangle may contain good building stones in some places, but no quarry of good limestone for building is known. There are several reasons for this lack of good stone, the chief of which perhaps are the shattered character of the rock, the irregularity of the joint planes, the curvature of the beds, and the presence of numerous veins of calcite and quartz. All these features are the result of the intense compression to which these rocks have been subjected at different times since their deposition. Another defect is the irregularity of the beds and their great variation in grain and thickness owing to the frequent recurrence of shallow water during the periods of deposition. Many of the limestones are ripple marked and sun cracked, and thin beds with shale partings or even beds of shale or sandstone alternate with thick beds of limestone. For these reasons rectangular blocks of rock are difficult to obtain without the removal of an excessive amount of waste rock, and the cost of labor required to quarry and dress the stones is prohibitive. Some of the strata in certain quarries might be used to advantage for building and the less desirable stone for ballast or for fluxing material.

Another objection to some of the limestones for building is their change of color on weathering. Most of the limestones are dolomitic, but the magnesium content differs in the different layers. When fresh the rock is all bluish, but on weathering the more dolomitic layers become much whiter than the others. The limestones that border the cement rocks contain considerable sand in irregular masses and have a tendency to become blotched by weathering, on account of their heterogeneous composition.

Notwithstanding these objections, however, which spoil them for the better grades of building stone, the limestones of the region have been used in the past for foundations and occasionally for buildings and will no doubt long continue to be quarried for local use.

Sandstones. The Cambrian sandstones along the slopes of the mountains have been more extensively quarried for building than any other rocks of the quadrangle. These sandstones are known to the building trade as the Potsdam sandstones or quartzites, although they do not belong geologically to the Potsdam sandstone but to the much older Hardyston quartzite. This rock has been extensively quarried along the end of the mountain three-quarters of a mile west of Iron Hill, along the mountain opposite the west end of Calypso Island and farther west, in several places near Aineyville, east and northeast of East Allentown, and three-quarters of a mile northeast of Hellertown. Although the same formation is well developed in other parts of the quadrangle the rocks have been largely metamorphosed in many places to a compact taffy-yellow chert in which all bedding planes have been obliterated and the rock has been locally so broken or brecciated as to be unfit for building stones.

The Cambrian sandstones that have been quarried are composed of quartz sand and a few pebbles, the largest of which are a quarter of an inch in size, firmly cemented with silica. When fresh the rock is bluish white in color, but as it contains some finely disseminated pyrite the rock on exposure to the weather, both in buildings and in outcrops, changes to a dull yellowish-gray tint that makes a pleasing appearance. The stone is so compact that it possesses very great strength and does not disintegrate from the action of frost. In the quarries the beds are fairly uniform and in most places are from 10 to 18 inches thick. The joints are regular and readily permit the quarrying of rectangular blocks of suitable size.

The available quantity of these Cambrian sandstones is small, and several of the quarries were abandoned on account of the exhaustion of the easily quarried material, yet in other localities near by good stone can still be obtained. In most places the quarries were opened on hillsides where there was little overburden, and the quarries were abandoned when it became necessary to remove much waste rock.

Many large buildings have been constructed of these sandstones, among which the principal buildings of Lehigh University—Packer Hall, the chemistry building, the library building and the new memorial building—are the best known. Packer Hall, erected in 1869, is the largest building in the region built of this stone.

The Triassic strata of the southeastern portion of the quadrangle contain some sandstone beds that have locally been used for build-

ing stone. In the vicinity of Hummelstown, Pa., and in the Connecticut River valley the Triassic strata furnish excellent sandstones that have been widely used, but in the Allentown quadrangle the sandstones are too full of shaly partings or are interbedded with so many thin beds of useless shale that it is doubtful whether they will ever be extensively quarried. They will, however, continue to furnish small quantities of stone of fair quality for local use.

Interbedded with the Ordovician black shales and slates (Martinsburg shale) in the northwestern portion of the quadrangle are local layers of brown sandstone suitable for building stone. These beds are most numerous in the vicinity of Kreidersville, where they have been utilized for foundations and for a few barns and houses. The color is objectionable for residences, and the beds are not uniform in thickness or in composition.

Gneisses. Elsewhere in Pennsylvania the gneisses have been extensively quarried for structural stone, but in the Allentown quadrangle they have been little used, probably in the main because a quarry must be opened at considerable expense before the quality of the rock can be definitely determined. On the surface the gneisses of all kinds are so broken by the action of frost or so greatly decomposed that a large amount of work would be necessary to reach good stone. Below the zone of freezing the stone is broken by joints into large irregular blocks that could be handled only by expensive mechanical equipment. The irregularity of the joints would cause an excessively large amount of rock to be discarded as waste, although this condition may not prevail everywhere. As large quantities of crushed rock for concrete and ballast are required in the industries of the region and in the making of permanent roads, market might be found for the rock that is unsuited for building stone.

The gneisses of the quadrangle furnish a wide variety of stones, ranging from dark-brown hornblendic to light granitic rocks, some of which are beautifully banded and others present a uniform appearance. In general the darker gneisses are more common in the eastern part of the quadrangle, especially in the vicinity of Hexenkopf Hill, and the lighter-colored ones are more abundant in the region between Bethlehem and Vera Cruz.

The gneisses contain no objectionable minerals except in a few localities, where pyrite is a common constituent. The chemical and physical character of the rocks renders them very durable as building stones under all climatic conditions. The economic possibilities of opening quarries in the gneisses should be investigated.

Diabase.—Diabase or trap rock, a dark fine-grained igneous rock occurring in the southeast part of the quadrangle, has been used for a few buildings. It is being quarried in the 880-foot hill 2 miles east of Coopersburg by the Coopersburg Granite Co. and by E. W. Brad-

ford for use as cemetery monuments. A large stone-polishing shop built at Coopersburg in 1923 is operated by the Coopersburg Granite Co. This bluish-black rock with fine granitic texture takes a good polish.

SLATE.

For full discussion of origin, composition, texture, quarrying, testing, and uses of slate, see Dale, T. N., and others.[61]

General Characteristics of the Martinsburg shale.

The northwest corner of the quadrangle is underlain by shales and slates that belong to the Martinsburg shale (long called "Hudson River slates"), of Upper and Middle Ordovician age. These beds constitute part of a great band that extends almost uninterruptedly from New York to Alabama and contains workable slate beds in many places. In Pennsylvania the band is from 5 to 8 miles in width and extends across the State in a curve from New Jersey on the east to Maryland on the south. The formation consists of about 3,000 feet of shales and slates, sandstones, and limestones. Workable slates are not everywhere present in the formation but occur only at certain horizons in a few counties of the State, chiefly in Lehigh and Northampton counties. In these counties good slates are found in two bands that extend from Delaware River about 42 miles to the southwest.

In this region the formation can be roughly divided into three members. The lower member consists almost entirely of shales which only locally contain beds of limestone or sandstone; the middle member contains many thick and thin beds of brown, locally calcareous, sandstone; and the upper member is composed of shales with few sandy strata. The lower and upper members contain many beds that have been so thoroughly metamorphosed that they now yield high-grade slate, but the middle member, on account of its massive sandstone beds, was not sufficiently compressed to convert the interbedded shales into workable slate.

The slate of the lower member is relatively hard because of the greater amount of siliceous matter and has long been known as the "hard vein" slate. It is worked in many quarries at Belfast and Chapmans, a short distance north of the Allentown quadrangle.

The upper member of the formation contains the quarries that are so extensively worked at Bangor, Penn Argyl, Wind Gap, Slatington, and Slatedale. The slate of this member is softer and is known as the "soft vein" slate.

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[61] Dale, T. N., and others, Slate in the United States: U. S. Geol. Survey Bull. 586, 1914.

Slate Deposits.

Distribution. In this quadrangle the lower member of the Martinsburg shale, which contains the "hard vein" slate, extends from the boundary of the cement rock northwestward to a line that passes near Kreidersville and Beersville. The middle member contains much sandstone, and no workable slate crops out along Hokendauqua Creek from Kreidersville northward beyond the boundaries of the quadrangle. The upper member lies wholly to the north of the quadrangle. All the quarries shown on the map (Pl. II), except No. 19, are opened in the lower member.

Although all the quarries thus far operated are along the headwaters of Catasauqua and Monocacy creeks and their tributaries, the same strata underlie the intervening divides. The slate has been quarried in the valleys on account of the deeper cover of decayed rock on the divides.

Throughout the belt where the quarries are situated workable slate is not everywhere obtainable, but good beds can be found by prospecting in many places besides those where quarries have already been operated.

Structure.—The strata that contain the slate of the region have been greatly deformed by intense compression, by which they have been thrown into close folds. In most of the quarries of the region there are synclinal folds that have a general northeastward trend. In many places the synclines are overturned so that both arms dip to the southwest at low angles. In other places the beds on the southeast limb of the fold, locally called the "incrop" beds, dip steeply to the north, whereas the beds on the northwest limb, called the "outcrop" beds, dip to the southeast at low angles. The "incrop" beds contain the best slate, although they are thinner than the beds on the trough of the syncline, called the "turn," or than the "outcrop" beds, owing to the greater squeezing to which they have been subjected. The complicated folds in the region make the exact correlation of particular beds in different quarries impossible except where excavations or borings are close together. In the Slatington and Bangor regions the position and location of the most valuable beds are fairly well known, but in the Allentown quadrangle the available information does not warrant even an approximate correlation, although the same beds have probably been worked in several of the quarries.

Character.—The slate of the quadrangle is considerably harder than that found at Slatington and Bangor and justifies the name of "hard vein" slate. The hardness and brittleness of the roofing slates made from this material cause many of them to break when nail holes are punched in them unless considerable care is exercised.

In general the ribbons are more numerous, thinner, lighter in color, and less liable to serious disintegration than those in the "soft vein" slates. Pyrite can be easily detected in much of the material, but as it occurs in isolated crystals its decomposition does not greatly weaken the slates although it slightly discolors them. Calcite and quartz veins, both called "spar" by the quarrymen, are abundant in places and tend to follow the bedding and cleavage planes. For several feet on either side of the veins the slate does not split readily and is consequently discarded as waste.

The slates, which are bluish black when fresh, fade on exposure to a light gray yet are very durable, as some slate roofs in the region are said to be more than 60 years old. The change in color is accompanied by a slight change in chemical composition, by which the carbon, the pyrite, and the small amount of carbonates of lime and magnesium are removed.

The following partial analysis of slate from Daniel's quarry was made by E. H. S. Bailey[62] at Lehigh University.

Partial analysis of slate from Daniel's quarry.

S	1.29
CO_2	2.72
$CaCO_3$	6.18

The specimen had a specific gravity of 2.78 and an index of porosity of 0.14.

Origin.—The slates of the region are metamorphosed mud deposits which were laid down in a sea that existed in the region during later Ordovician time. In certain places calcareous deposits were formed which now constitute the interbedded limestones that are exposed near Seemsville; in other localities sandy deposits were formed.

The change from the shales to slate was effected by the great earth movements that were most active at the ends of the Ordovician and Carboniferous periods, during which the strata were thrown into complicated folds. The compression also caused the formation of new minerals, chiefly muscovite (sericite), vein and chalcedonic quartz, chlorite, pyrite, magnetite, hematite, and carbonates of lime, magnesia, and iron. These minerals all tended to arrange themselves with their flat sides and long diameters parallel to the direction of the compressive force. The abundance of parallel grains of muscovite and chlorite which readily separate into thin cleavage flakes, is the cause of the excellent cleavage which slate possesses in distinction from other classes of rocks and to which it owes its chief value. The same metamorphic forces cemented the individual layers of slate so thoroughly that the rocks no longer separate readily along the

62 Am. Soc. Civil Eng. Trans. vol. 22, p. 542, 1894.

bedding planes, and in many places it is difficult to measure the dip and strike of the beds in order to determine the structure. The layers differ somewhat in composition, and consequently it is possible to determine the original beds on a cleavage surface by the bands of different colors that cross it. These bands or beds that differ in color and composition from the main mass of the rock form the "ribbons" of the slate.

During or subsequent to the conversion of the shale into slate openings were formed in the rocks in which percolating waters precipitated quartz and calcite. In the disintegration and removal of the slate the masses of quartz were left as a residuum and are very common in the soil of the slate hills. South of Miller's quarry and in the other places great masses of vein quartz several feet in diameter are piled along the fences, where the farmers have thrown them in clearing the fields.

The slate disintegrates near the surface and forms a clay soil filled with thin flakes of less thoroughly decomposed slate. As decomposition and consequent disintegration of slate take place the property of even cleavage disappears, so that it is necessary to remove a considerable thickness of material in places before reaching good slate. For this reason quarrying on the tops of hills, where erosion has removed less of the decomposed cover, is more expensive than in the valleys.

Uses.

Most of the slate produced in the quadrangle has been used for roofing material. So common are slate roofs in the region that almost every shed or structure of any kind is covered with slate. Many houses even have slate shingles on the sides as well as on the roofs. The next largest quantity of slate has been used in sidewalks in the towns of the section. At present concrete walks are gradually replacing the old slate ones.

Much slate has also been used for fence posts, and in some places near the quarries scarcely any wooden posts are seen. The slate posts are not very desirable, however, as they disintegrate by frost action and also have a tendency to lean to one side as they settle into the ground because of their weight. In some places fences are made by cutting large holes in the slate fence posts into which boards are fitted that extend from post to post. In other places boards are bolted to the posts and wire fencing is nailed to these boards. The posts are generally made about 12 to 14 inches wide and 2 inches thick. (See Pl. XI).

Some slate has also been used for steps, gravestones, foundations, and walls. For these purposes the refuse of the quarries is suitable, but the demand is so small that only a little of the material unfit for roofing slate can be utilized, and beside every quarry there is a great heap of waste material that seems to be approximately as large as the quarry opening.

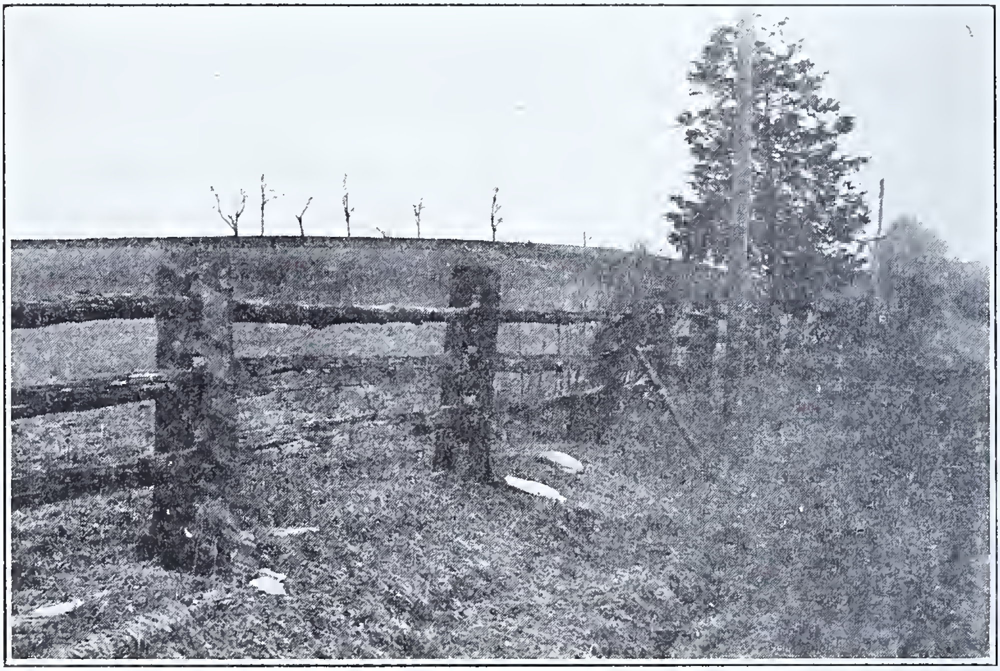

Plate XII. Slate fence posts near Bath, Pa.

Economic considerations.

For many years the slate industry of this region has been in an unsatisfactory condition and few of the quarries have been operated full time. At many quarries the men have been given employment only two or three days a week for months at a time. The quarrymen find that it is not advisable to accumulate a large stock of finished slate, for it changes color through fading sufficiently to lower the selling price, especially if stored in the open air, although its wearing qualities are not lessened, and consequently, when building operations are slack, the quarries must curtail their output. As the amount of slate available is very great and the quarries are operated independently, there has been ruinous competition, which has forced the less favorably located quarries to close. All the old slate quarries of the quadrangle were from 1 to 3 miles from the nearest railroad so that naturally they could not compete with those of adjoining regions in close proximity to railroads. The quarry of the Achenbach Slate Co. did not share in this disadvantage, as it is along the Lehigh & New England Railroad.

Under present conditions the slate industry of the quadrangle will probably never again be restored to its former activity. Whenever the need arises for additional slate quarries in this general region, however, the demand can be supplied.

Slate Quarries.†

1, 2, 3. No data could be obtained in regard to these old slate quarries, which have long been abandoned. They are now filled with water and no rock is exposed.

4. *Miller's slate quarry.*—This quarry furnished more slate than any other in the quadrangle but has been idle since 1904. It is said to have been worked for about 50 years. The pit, which is now filled with water, measures approximately 250 by 200 feet in area and is said to be 130 feet deep. The structure of the beds cannot be determined because the rocks are poorly exposed. Along the southeast side of the quarry the strata strike N. 70° W. and dip 28° SW. The slate obtained from this quarry was of good quality, even though it contained numerous ribbons. The expense of hauling the slates to the railroad was perhaps the principal reason for closing the quarry.

The following description of this quarry is given by R. H. Sanders.:[63]

"Chester County quarry is 200 by 250 by 130 feet deep. The slates dip 20° S. 40° W. Cleavage horizontal. At 10 to 40 feet from the top of the cut, veins of quartz show parallel to the bed plates. The slates are all thin bedded and the beds differ slightly in color. Some few of the slates have a small amount of iron pyrites in them. The blocks coming out of the quarry are large and even in size. Some of them are 20 feet long, 4 feet wide, and 2 feet thick but do not seem to split well. There is a little water in the quarry. It is worked by two cable derricks, run by one 40-horsepower engine."

5. *Hower's quarry.*—This is a long-abandoned quarry along a small tributary of Catasauqua Creek. The opening, now filled with water, measures about 50 by 50 feet. The structure can not be determined in the weathered rock exposed near one side of the pit.

6. *Ziegenfuss quarry.*—Abandoned quarry that is filled with water. The pit measures about 100 by 175 feet and is said to be about 50 feet deep. The structure is not determinable, but the strata that were observed dip about 30° S.

7. *Ziegenfuss quarry.*—At this quarry the great pile of waste slate and the size of the opening, which measures about 150 by 100 feet, indicate extensive quarrying, although nothing has been done here since 1900. The strata dip 15° N. and the cleavage 5° S. The slates are thin bedded and contain some iron pyrites.

8. This opening along a creek is a small pit that has been long abandoned, and no data are obtainable.

9, 10. These two abandoned quarries are filled with water. Each measures approximately 150 by 150 feet. Only a small area of

[63]Pennsylvania Second Geol. Survey, Rept. D3, vol. 1, p. 106, 1883.
†The numbers refer to similar numbers on the map (Pl. II).

strata is exposed. On the south side of No. 9 a small synclinal fold overturned toward the north is exposed. The cleavage is about 20° SE. Some iron pyrites are present in the slate.

11. A small abandoned slate quarry that is filled with water. No data could be obtained.

12. A small quarry along the roadside. Very little slate was quarried here.

13. *Achenbach Slate Co's. quarry.*—This quarry is the only one recently in operation in the Allentown quadrangle. The quarry was opened in April, 1914, and produced about 230 squares of roofing slate by the close of the season. The quarry was too shallow to yield the best slate, but the material was promising. A 4-inch core drilling to the depth of 75 feet showed several good beds of slate. Three bands of spar and crooked slate were penetrated at depths of 13, 38, and 60 feet. The material obtained was graded as No. 2 and No. 3 and was sold for $3.25 to $3.50 a square.

14. This is a small abandoned quarry, which shows indications that the material was used on the roads, as the rock seems to be too greatly weathered to have furnished any roofing slate.

15. This is a small abandoned quarry. The beds dip 10° S. and the cleavage is 15° S.

16. *Daniel's quarry.*—This quarry is the oldest in the region. It is said to have been first opened in 1836. The quarry is filled with water, which prevents any observations of the structure. The beds seem to dip to the southeast at an angle of about 20°. The slate contains many fine ribbons.

R. H. Sanders[64] gave the following description of this quarry:

> "Daniel's quarry is abandoned and full of water, 250 by 150 feet, probably about 40 feet deep. The slates are thin-bedded with a flat dip and cleavage of 20° S. Some of the slates on the pile have about 10 beds in them. There are about 50 squares on the pile; most of them have iron pyrites in them at the junction of the ribbons; the slates on the end of the pile have changed color. Some of them have also thin veins of quartz in them."

17 and 18. These are two small abandoned slate quarries.

19. This is an abandoned slate quarry $1\frac{1}{4}$ miles northwest of Lanark and is the only place in the Saucon Valley where workable slate occurs. It is not a true slate but a very slaty limestone. The quarry furnished considerable stone that was used for pavements, steps, and gravestones. No roofing slates were produced. The strata dip to the south.

MATERIALS FOR CRUSHED ROCK.

The rocks of the Allentown quadrangle include a vast quantity of material suitable for crushed rock for road metal, ballast, and concrete. The construction of new concrete buildings for the larger industries, the building of bridges, the paving of streets in the towns

[64]Pennsylvania Second Geol. Survey, Rept. D3, vol. 1, p. 102, 183.

and cities, the macadamizing of many roads, and the extension of trolley lines and railroads have demanded an enormous amount of crushed rock, most of which has come from quarries within the quadrangle, and much of this material has been furnished to other sections. For these purposes the limestones have been most extensively used, although the sandstones, gneisses, and diabase have also been quarried in some places.

Limestones.—The map shows that nearly all the railroads of the quadrangle are confined to the limestone areas and following along streams that are bordered by bluffs in many places 100 feet in height. These conditions favor the quarrying of limestone, because a good quarry face can be easily developed and transportation facilities are close at hand. So numerous are the quarries that it would be useless to attempt descriptions of them. Some of the largest are near Redington, Freemansburg, Hellertown, Bethlehem, East Allentown, Allentown, Catasauqua, Coplay, Shoenersville, Nazareth, and Tatamy.

The rock quarried in almost all places is covered with a minimum amount of rotten limestone, residual clay, or glacial debris. An average thickness of approximately 4 feet only must be removed from the surface. The surface, like that of most other limestone regions, is very irregular and contains many pits or pockets, so that in some parts of a quarry the top cover may be practically absent whereas close by the clay may be 15 feet or more in thickness. In structure the limestones show great variations. The complicated folds of the region can be observed in hundreds of places. Some quarries contain beds that are almost vertical, in others the strata are nearly horizontal, and in others the rocks are so greatly crumpled and faulted that the bedding planes can be traced only with difficulty. The more intense the folding the more shattered are the rocks and consequently the more easily are they crushed. Open fissures and small caves formed by solution are not uncommon, and in some of them excellent specimens of stalactites and stalagmites can be obtained. Some fine blocks of cave onyx are occasionally found but not in sufficient quantities to be of economic importance. In some places the cavities have been filled with clay.

Shale layers are numerous in the limestones close to the gneiss, and in some places are a serious handicap in the successful operation of the quarries. Concretionary masses or lenses of black chert are also present in many places and locally veins of quartz.

Many quarries produce from 20,000 to 25,000 tons and some as much as 80,000 tons a year. The price depends on the size to which the rock is crushed.

Sandstones.—For certain purposes rocks harder than limestones are desired, and the siliceous sandstones and gneisses are crushed

to supply this demand. In many places where the Cambrian sandstones have been quarried primarily for building stone some of the rock has been crushed. Crushed sandstone has been furnished by quarries half a mile southeast of Emaus, along the Lehigh Valley Railroad west of Bethlehem, south of Emaus, and west and southeast of Springtown. In comparison with the amount of crushed limestone, however, the amount of crushed sandstone furnished by the region is very small, owing to the greater expense of crushing the rock, its greater distance from the railroads, the amount of hillside wash that so generally covers the beds, and the difficulty of obtaining good quarry faces, such as can be readily obtained in the limestones.

The larger pebbles and cobbles of siliceous sandstones found in the extensive deposit of glacial material along the trolley line a short distance northeast of East Allentown were separated from the sand and finer pebbles and crushed for ballast.

Gneisses.—The gneisses of the quadrangle have been used to furnish a little crushed rock. In places temporary rock crushers have been set up to utilize the gneiss boulders that have rolled down the sides of the mountains. Some years ago one of these crushers was operated about 1½ miles northeast of Limeport for several months. The largest quarry that has been opened in the gneiss to furnish crushed rock is three-quarters of a mile east of Vera Cruz. The rock, which is a very dense granitic gneiss, is of considerable scientific interest because of the presence in it of small amounts of molybdenite and uraninite. The quarry has been idle for several years, and the crusher is now dismantled. Another quarry is near the top of the mountain along the trolley line between Bethlehem and Seidersville. This quarry has furnished much crushed rock but is now idle. The rock is a compact dark banded gneiss.

In many of the sand quarries in the decomposed gneiss the more resistant, less thoroughly disintegrated masses of rock are crushed for ballast. This material makes a smooth road, as the rocks are ground fine in a short time and the kaolin acts as a binding material in dry weather, but the coating must be renewed frequently.

Diabase or trap rock.—Throughout this region great quantities of dark igneous rocks, mostly diabase but known in the trade as traprock, are used as ballast. Considerable rock of this kind occurs east and southeast of Coopersburg and in the extreme southeast corner of the quadrangle. The most promising location for a trap-rock quarry is the 880-foot hill about 2 miles east of Coopersburg, where the rock is quarried for monuments. A short distance south of the borders of this quadrangle similar rock is extensively quarried for crushed stone, especially at Rock Hill, 3 miles southeast of Quakertown.

For railroad ballast and for macadam roads trap rock is one of the best materials known, and an extensive industry can be developed in this region when market conditions warrant the opening of new quarries. Competition with quarries favorably located and already in operation has been the principal factor in delaying the utilization of the trap rock of this quadrangle.

ROCKS FOR PAVING BLOCKS.

Diabase or trap rock as it is generally called by contractors, is one of the best kinds of rock for paving blocks. Although none of this material has been quarried in the Allentown quadrangle several carloads of blocks made from the loose masses of rock from the 880-foot hill east of Coopersburg have been shipped to Philadelphia for street paving. The few men employed claim to have made good wages. The rock, which is very compact, dark gray, and medium coarse-grained, can be readily trimmed to the desired shape and size. The small demand at the present time for this material is the principal obstacle to the development of the industry. A quarry in similar rock a short distance south of this quadrangle was operated for several years and produced a considerable output of paving blocks, but the demand has decreased.

LIMESTONE USED FOR LIME.

On the map (Pl. II.) 300 limestone quarries are shown, and numerous small openings have been omitted. Most of these quarries have been operated to obtain material for lime. At one time almost every farmer had a limekiln on his farm where he burned enough lime for his own use. If rock could be obtained readily on his own land he opened a quarry of his own, but if not he hauled the stone from near by quarries. Limekilns are numerous even in the areas of gneiss or slate several miles distant from the nearest limestone outcrops.

For many years the use of lime as fertilizer has gradually decreased, and the lime so used is obtained from places where large kilns are in continuous operation. The expense of quarrying the rock and burning a few hundred tons a year was excessive, and frequently the lime obtained was imperfectly burned. Consequently, as facilities have improved for obtaining lime from other regions where uniform material could be secured, scores of kilns were allowed to fall to pieces, and the quarries were abandoned. Though many farmers still use lime on their fields there is no doubt that the quantity of lime used in fertilizing the soils is much less than when the farmers owned and operated their own kilns. The heavy clay soils of the limestone region, although formed from calcareous rocks, as well as the soils formed from the other kinds of rocks, are deficient

in lime, and unquestionably a more general use of lime would be advantageous, in the improvement of both the chemical and physical properties of the soils. The lime made in the region has also been widely used for plaster.

At the writer's suggestion S. H. Salisbury, Jr., and G. C. Beck analyzed numerous samples from five different quarries in the Ordovician limestones of the Allentown quadrangle. From their published results[65] the following extracts are taken to show the variations in the chemical composition of some of the magnesian limestones that have been so extensively quarried for lime.

Quarry A.

Quarry A is situated in Northampton County three-eighths mile west of Georgetown on the Newcenterville road, and is 1⅞ miles from the northern boundary of the quadrangle. The strata here are nearly vertical and vary in thickness from 2 to 8 feet. Near the center some folding and faulting occur so that it is difficult to follow the strata to the top of the quarry.

Analyses of limestone from quarry A. Allentown quadrangle, Pa.

Sample	Thickness of beds (feet).	MgO	$MgCO_3$	SiO_2	R_2O_3	CaO
A1a	South face	15.41	32.20			
A1b	South face	17.14	35.84	5.82	1.23	28.19
A1c	South face	16.81	35.12			
A2	2¼	18.95	39.60			
A3	3⅓	17.09	35.72			
A4	7¼	16.78	35.05	10.35	5.25	47.08
A5	3⅙	18.00	37.64			
A6	3⅓	18.45	38.54			
A7	6½	18.48	38.74			
A8	4	17.32	35.20			
A9	2¼	17.56	36.65	7.35	3.85	29.56
A10	6⅚	17.72	37.04			
A11	2 7/12	18.33	38.34			
A12	2	17.12	35.80			
A13	8½	18.68	39.00			
A14	2¼	17.59	36.67			
A15	1⅙	15.29	31.93			
A16	North face	18.40	38.47	8.92	2.90	27.48

Highest is A13, 18.68 per cent. Lowest is A15, 15.29 per cent. Greatest difference, 3.39 per cent. Average 17.51 per cent.

These results show quite small variation, considering the number of strata, the greatest difference being 3.39 per cent. The average of the CaO seems to be about 28.41 per cent. Sample A4 shows a very large increase in CaO with a drop of 0.8 per cent MgO from the average of the quarry. This large increase of CaO in sample A4 over the beds A1b and A9 on both sides of it is significant.

Quarry B.

Quarry B is located in Northampton county, one-half mile north of Brodhead on the Nazareth turnpike, 4⅜ miles from the northern boundary and 4½ miles from the eastern boundary of the quadrangle. This quarry faces the west, is 700 feet long and about 30 feet high, with bedding and cleavage planes nearly indistinguishable. Samples were taken every 35 feet at various heights from the base.

[65] Jour. Indu. and Eng. Chemistry, vol. 6, pp. 837-851, 1914.

Analyses of limestone from quarry B, Allentown quadrangle, Pa.

Sample	Height from base (feet).	MgO	$MgCO_3$	SiO_2	R_2O_3	CaO
B1	3	19.13	39.98	2.36	1.97	28.89
B2	10	20.49	42.83			
B3	20	18.68	39.04			
B4	15	19.94	41.68	7.70	3.85	28.29
B5	13	20.16	42.14			
B6	3	19.43	40.61			
B7	25	19.98	41.76			
B8	5	20.25	42.32			
B9	10	29.35	42.53			
B10	8	20.54	42.93			
B11	15	20.47	42.78	1.74	1.17	29.43
B12	10	19.75	41.28			
B13	25	19.88	41.55			
B14	7	19.29	40.32			
B15	7	20.37	42.57	2.45	0.93	29.50
B16	7	20.34	42.51			
B17	7	19.85	41.49			
B18	7	18.79	39.27			
B19	7	20.16	42.14			
B20	7	19.00	39.71			

Highest, B10, 20.54 per cent. Lowest, B3, 18.68 per cent. Greatest difference, 1.86 per cent MgO. Average 19.84 per cent MgO.

The results here, as might be expected from the structure, show less variation than in quarry A, while the average is 2.3 per cent higher. The greatest difference is only 1.86 per cent MgO, this quarry being the most regular in the distribtion of the magnesia of any that we have analyzed. The lime content is also quite regular, the greatest variation of any of the constituents being in the percentages of silica.

Quarry C.

Quarry C is located in Lehigh County, about 100 yards north of the Coplay station of the Lehigh Valley railroad, three-eighths mile from the western boundary of the quadrangle and 6¼ miles from the northern boundary. The beds here are of varying thickness, are vertical or nearly so, and some of them are intricately folded.

Analyses of lime-stone from quarry C, Allentown quadrangle Pa.

Sample	Thickness of beds (feet).	MgO	$MgCO_3$	SiO_2	R_2O_3	CaO
C0		13.29	27.72			
C1	4⅓	17.54	36.66			
C2	2⅓	15.10	31.56			
C3	8	0.97	2.03			42.64
C4	15	0.76	1.40			54.58
C5	2⅙	16.72	34.95			
C6	1 1/12	8.46	17.68	15.57	5.36	32.77
C7	1½	15.57	32.54			
C8	2	15.16	32.31			
C9	8⅓	0.87	1.82			53.47
C10	3⅔	13.76	28.76	12.38	6.30	32.34
C12	2⅓	16.98	35.49			
C13	1 7/12	16.47	34.42			
C15	1¾	15.66	32.73			
C16	2 7/12	17.33	36.22	6.22	3.96	29.22
C17	1¼	16.19	33.84			
C18	2	14.41	30.12			
C19	4	1.52	3.18			
C20	4⅓	12.58	26.29			
C21	1⅔	16.77	35.05	6.44	4.60	28.61
C22	1⅔	14.29	29.87			
C23	1½	16.64	34.78	6.01	5.13	29.73

The highest is C1, 17.54 per cent MgO and the lowest is C20, 12.58 per cent MgO. This is with samples 3, 4, 6, 9, and 19 excluded. The average is about 15.58 per cent of MgO.

The very low per cent of MgO in samples 3, 4, 6, 9, and 19 can be accounted for by an inspection of the hand samples, each of which shows crystals of calcite

scattered throughout the groundmass. All these samples effervesce greatly with cold dilute hydrochloric acid and the analysis shows them to be nearly pure limestone. In connection with the high lime, the high silica and low magnesia in samples 6 and 10 are to be noted.

Quarry D.

Locality D is located in Lehigh County about one-half mile north of Friedensville, 4¾ miles from the southern boundary, and 5½ miles from the western boundary of the quadrangle. This location is an abandoned zinc mine, and the beds are nearly vertical, while the hand specimens show considerable weathering.

Analyses of limestone from locality D, Allentown quadrangle, Pa.

Sample	Thickness of beds (feet).	MgO	$MgCO_3$	SiO_2	R_2O_3	CaO
D1	4⅚	18.11	37.88			
D2	6⅔	19.60	40.98			
D3	5⅓	19.20	40.15	6.40	1.39	18.23
D4	2⅔	19.79	41.38	3.89	1.40	28.33
D5	4⅚	18.33	38.34	8.91	2.31	27.44
D6	1	19.56	40.90	6.75	2.75	28.10
D7	3⅙	19.00	39.73			
D8	4⅓	16.80	35.13			
D9	3½	16.62	34.75			
D10	6	16.54	34.59			
D11	3	12.95	27.08	13.60	3.31	22.75
D12	2½	15.59	32.60	13.61	3.48	24.33
D13	4½	17.97	37.58			
D14	3⅔	17.69	36.90			
D15	7⅓	18.62	38.93			
D16	11 7/12	16.39	34.27			
D17	4	19.09	39.92			

Highest D4, 19.79 per cent MgO. Lowest D11, 12.95 per cent MgO. Greatest difference, 6.84 per cent MgO. Average, 17.87 per cent MgO.

This quarry shows the greatest difference in magnesia of any of the quarries, yet the average is within about 0.3 per cent of that of quarry A, located near the northern boundary of the quadrangle. These beds are characterized by rather low lime content and high silica. In particular samples 11 and 12 show, for reduced magnesia, an increase in silica rather than in lime, as might be expected.

Quarry E.

Locality E is located in Northampton County, one-eighth mile west of quarry B, being a cut of the Lehigh & New England railroad. The beds are sharply inclined to the north.

Analyses of limestone from locality E, Allentown quadrangle, Pa.

Sample	Thickness of beds (feet).	MgO	$MgCO_3$	SiO_2	R_2O_3	CaO
E1		16.97	35.47	12.03	4.06	29.03
E2	⅔	15.00	31.35	8.71	4.53	28.26
E3	2⅚	11.45	23.93	12.25	1.30	16.62
E4	1½	14.59	30.49			
E5	1⅔	13.60	28.42			
E6	4⅙	13.87	28.99	8.08	5.39	24.54
E7	1½	7.58	15.85			
E8	4⅓	12.65	26.44			
E9	1½	15.77	32.96			
E10	⅔	14.71	30.74			
E11a	6⅙	16.38	34.23			
E11b	6⅙	13.18	27.55	21.52	8.10	18.08
E12	1	6.70	14.00			
E13	1⅚	14.64	30.60			
E14	¼	14.51	30.33			
E15		18.36	38.37	5.20	3.08	31.42
E16	2⅚	16.01	33.45	2.55	3.76	33.63
E17	2⅙	9.75	20.38			
E18	6⅔	16.86	35.24			
E19	9	14.84	31.02			
E20		14.76	30.85			

Highest E15, 18.36 per cent MgO. Lowest E8, 12.65 per cent MgO, excluding samples 3, 7, 12, 17. Greatest difference, 5.71 per cent MgO. Average, 15.10 per cent MgO.

Samples 3, 7, 12, and 17 are excessively low in magnesia. Inspection of the hand specimens shows that 3 and 17 contain crystals of calcite throughout the groundmass, while 7 and 12 are clay shales and give off an earthy odor when breathed upon.

The difference in content of lime is also to be noted, ranging from 16.62 per cent in E3 to 33.63 per cent in E16, a difference of 17 per cent. There is also considerable variation in the silica.

LIMESTONE USED FOR FLUX.

The numerous iron furnaces of the region have required a great amount of limestone for flux, which has largely been obtained within the region. Occasionally limestones from this quadrangle have been shipped to adjacent areas. The Parryville Iron Co. at Parryville long obtained fluxing limestones from a quarry near Northampton, and the New Jersey Zinc Co. operates a quarry at Allentown to obtain fluxing material for use at Palmerton.

Nearly all the quarries from which stone is obtained for flux are situated along the railroads, and spurs are built into the quarries. In many places better material might have been obtained elsewhere, but the cost of hauling the stone to the railroads was prohibitive.

Although the limestones have been and still are being extensively used for flux, there are some objectionable features which have inconvenienced the operators, the worst of which is the presence of layers that run high in silica. Most of the furnace operators prefer limestones that contain less than 4 per cent silica, and where shaly or sandy strata are interbedded with the limestones it is necessary to separate these beds as waste rock. The presence of solution cavities filled with clay, which are common in regions where the rocks have been deformed or shattered by earth movements, is equally objectionable. Clay filling deep solution pockets in the surface is also present in places, and the removal of this overburden greatly increases the cost of quarrying.

The Bethlehem Steel Co., the largest consumer of limestones for flux in the district, uses much local stone but also imports a great deal from New Jersey which is lower in silica.

The following analyses of local limestones have been selected from hundreds made by the Bethlehem Steel Co., the Crane Iron Co., and the Thomas Iron Co., all of which have been largely dependent upon the limestones of the Allentown quadrangle for their fluxing material during the past half century.

Analyses of limestone used for flux.

	1	2	3	4	5	6
$CaCO_3$	51.60	88.12	52.8	47.66	53.67	53.20
$MgCO_3$	42.60	4.71	41.0	42.26	39.87	41.30
SiO_2	3.30	4.70	3.79	6.94	3.90	2.32
Al_2O_3	1.75	1.33	----------	1.95	.75	1.50
Fe_2O_3	.52	.26	----------	1.05	.53	

1. Quarry of New Jersey Zinc Co., East Allentown, W. Wyckoff, analyst.
2. Quarry of Calcite Quarry Co., Northampton, W. Wyckoff, analyst.
3. Average of many samples from Chapman's quarry of Bethlehem Steel Co., Freemansburg. Analyzed in company's laboratory.
4. Wagner's quarry near Hellertown. W. Wyckoff, analyst.
5. Bieber's quarry near Emaus. W. Wyckoff, analyst.
6. Eberhart's quarry, West Catasauqua. W. Wyckoff, analyst.

The average of 14 analyses made in the company's laboratory from the quarry of the Bethlehem Steel Co.. Redington, gave 3.77 per cent SiO_2.

QUARTZ-MICA SCHIST ("SOAPSTONE").

In several places in the areas of gneiss in the Allentown quadrangle there are rocks which contain large amounts of quartz, mica (sericite), and sillimanite. Rock in which the sericite is especially abundant feels "soapy" to the touch, somewhat like talc, and it is locally known as "soapstone." Actually it contains only minute amounts of talc. Under the misapprehension that the rock was soapstone quarries were opened in it just beyond the borders of the Allentown quadrangle, southeast of Smith Island (Island Park) and 1¼ miles southeast of Seidersville. From the Smith Island quarry the rock was hauled to Easton to be ground for paper filler. Some of the material from the other quarry was used several years ago for furnace lining by the Bethlehem Steel Co. It is reported to have been satisfactory for this purpose.

SAND AND GRAVEL.

The local demand for sand and gravel has resulted in the development of many deposits that in a less populous section would be disregarded. Four kinds of sand are dug, each of which is distinct in origin and occurrence and adapted more or less to different uses.

Decomposed gneiss.—The most abundant sand of the Allentown quadrangle is that obtained where the lighter-colored quartz-feldspar gneisses have decomposed into a mixture of angular particles of quartz and impure kaolin. Technically, decomposed gneiss should not be called sand, but in this section, where such material is used as a substitute for the ordinary kinds of sand, the commercial usage seems to be justified. The alteration of the feldspar to kaolin and the oxidation and removal in solution of the hornblende and pyrox-

ene causes the rock to disintegrate. As water which carries oxygen in solution is the most active factor in this change the decomposition starts along the joint planes of the gneiss and gradually extends into the blocks bounded by these fissures. Near the surface the alteration is practically complete, and all the rock is soft enough to crumble into sand when disturbed. At greater depths there are many masses of partly altered rock still so hard that they must be discarded when the material is quarried for sand. In some of these quarries these resistant blocks are passed through a rock crusher and screened, the finest portions being used for sand and the remainder for concrete work or road metal.

The gneiss sand pits, as shown on the map (Pl. II), lie along the slopes of the gneiss hills, especially near Bethlehem, Rittersville, Aineyville, Emaus, and Hellertown. Besides those shown on the map there are scores of other openings where at times a few wagonloads of sand have been dug.

The pits that are opened along the sides of the mountains increase in depth as the work progresses, and in some of them a 60-foot face is obtained. In some places the rock is decayed sufficiently to furnish sand at depths of 100 feet or even more.

In most of the pits there is an overburden of loamy clay and fresh gneiss boulders derived from the outcrops of gneiss higher up the mountain that must be removed. In few places is this surficial material more than 4 feet in thickness. The quarrying is done with pick and shovel, and the loose material is thrown against a sloping screen, the mesh of which differs according to the kind of sand desired. The particles which fail to pass through roll to the bottom of the screen. By pounding these coarser fragments with the back of the shovel many of them can be disintegrated sufficiently to permit them to pass through the screen when they are again thrown against it. The other pieces are thrown aside as waste or put through a stone crusher.

In some of the pits the decomposition of the gneiss is very irregular, and certain parts of the pits must be abandoned on account of the large amount of waste rock. In one place the gneiss may be thoroughly decomposed to a depth of 50 feet, whereas close by hard rock may come within a few feet of the surface. A few pits contain dikes of basic rock, and this material must be discarded. In a pit in Bethlehem two dikes of such rock carrying much biotite caused considerable inconvenience, as the material resulting from their decomposition was worthless and had to be separated from the other sand.

The gneiss sand is used for a variety of purposes. It is especially well adapted for a molding or core sand on account of the kaolin, which acts as a binder, and large quantities are used by the furnaces.

foundries, and pipe mills of the region. For plastering and brick work it is less desirable, as the presence of the kaolin is detrimental, but this is partly counterbalanced by the sharp angularity of the grains of quartz, which increases the strength of the plaster or mortar. The decomposed gneiss is widely used as a building and brick sand throughout the region. The coarse material is extensively used in concrete work and to a less extent for road metal.

The prices of the sand depend upon both the quality and competition. The waste material used for road work sells for a very low price. The industry is almost entirely local, although some sand is shipped to foundries and furnaces outside the quadrangle. The production, which varies greatly from year to year, averages from 20,000 to 25,000 tons.

Glacial sand and gravel.—Although an ice sheet covered almost the entire area of the Allentown quadrangle, workable deposits of glacial sands and gravels are comparatively few, as most of the glacial deposits of the region consist of clay and boulders. At the present time only one of these deposits is being worked for sand and gravel. It is located about 1¼ miles northeast of Emaus. For many years a deposit which underlies West Bethlehem was worked at several places, but the old pits are now largely filled. A large deposit formerly worked is situated about three-quarters of a mile northeast of East Allentown. Another deposit three-quarters of a mile south of Georgetown has also been worked.

The glacial gravels and sand are well stratified and consist mainly of well-rounded quartz or siliceous sandstone in a matrix of loose quartz sand. In some places the sand predominates, but in most places the sand is subordinate to the gravel.

In the deposit northeast of East Allentown that was worked by M. H. Bachman & Co., the upper 5 feet consist of plastic brownish-yellow clay beneath which are well-stratified pebbles, the largest of which are 3 inches in diameter, though the average is less than 2 inches. The matrix consists of loose quartz or loamy sand. Lenses of fine sand free from pebbles are present in parts of the deposit. The pebbles, which are abundant in certain places, consist mainly of siliceous sandstones and conglomerates, but pieces of limestone and rotten shale are not uncommon. Boulders several feet in diameter occur at the base of the section. The deposit is from 40 to 50 feet thick and rests on decayed limestone. It was worked by a cable excavator, the gravel being scooped up by a bucket and carried on a cable to the crusher house, where it was crushed to the size desired. Most of it was ground to a sharp sand which was well adapted for plastering, bricklaying, and concrete work. Some material that was not crushed so fine was used for roads. The annual production was about 20,000 tons.

Similar gravel seems to extend continuously to West Bethlehem, where a pit that is widely known as Rauch's gravel pit was operated for many years. The following section was exposed:

Section at Rauch's gravel pit[66]

	Feet
Clay holding boulders, large and often sharply angular, lying irregularly in the body of the clay. Of this clay there remains on the hill top, as quarried	4
Gravel and sand, horizontally stratified; destitute of boulders; the pebbles all water worn, none more than 3 or 4 inches long.	
Streaks of pure sand.	
Sand with oblique stratification.	
Gravel and sand, stratified, but not horizontally, gray, sandy, no clay	30+

Two wells in West Bethlehem show that the deposit of glacial gravel is 136 feet in depth.

The deposit 1¼ miles northeast of Emaus is composed mainly of sand and has been extensively worked. Much material has been shipped from this place for use in mortar and for foundry work. About 30 carloads a year are shipped.

Section at gravel and sand pit 1¼ miles northwest of Emaus.

Clay and fine gravel, not assorted	12
Stratified fine yellowish-brown sand which locally contains lenses of fine gravel	4
Very fine yellowish-brown sand containing some thin lenses of ocherous clay; exposed	17

Three-quarters of a mile south of Georgetown a sand and gravel pit was formerly operated in a deposit of glacial material, which consists of fine buff to yellow stratified sand overlain by 5 feet of red plastic boulder clay that contains pebbles and boulders of quartz, siliceous sandstones, and slate.

Alluvial sand and gravel.—Along Lehigh River there are alluvial deposits at many places, and the islands in the river are also composed of alluvial débris. In most places the alluvium consists of mud in which there is a large admixture of anthracite dust, but in a few places deposits contain much sand and gravel. Between Freemansburg and Redington the alluvial gravels have been dug for ballast in several places.

Sand from mud-dam deposits of limonite iron mines.—In the discussion of ocher (p. 153) a description is given of the character of the deposits formed in the mud in the ponds into which the waste material of the limonite mines was thrown. The coarsest sand was

[66] Pennsylvania Second Geol. Survey, Rep. D3, vol. 1, p. 48, 1883.

deposited near the place where the water entered the pond, and the finer sediment was carried farther out. This sand, which consists of small grains of quartz, quartz crystals, botryoidal chalcedony, thin flakes of limonite, and a few fragments of shale, limestone, and quartzite, is mixed with considerable ocherous clay. Even when the mines were in operation this sand was sometimes used for ordinary plastering and brickwork, and since the mines were closed sand for these purposes has been dug from many of the old deposits that are common throughout the region. In some places several feet of sand comparatively free from clay can be obtained, but in most places layers of clay are so closely interstratified with the sand that clean sand is hard to get. If the material were washed a large quantity of good sand could be procured from almost every mud-dam deposit in the quadrangle. Notwithstanding the difference in occurrence the sand from the limonite mines in the limestone and that from the mines in the quartzite are strikingly similar.

In working these deposits it is usually necessary to screen the material to remove any large fragments. The annual production of this type of sand in the quadrangle formerly averaged about 1,000 tons a year, most of which came from deposits about $1\frac{1}{8}$ miles southwest of Friedensville and 1 mile northeast of Hellertown. The sand was sold for 35 to 45 cents a ton at the pit, or 75 to 85 cents delivered.

CLAY.

Throughout the limestone regions of the Allentown quadrangle there are surface deposits of yellowish-brown or reddish-yellow clays which are suitable for the manufacture of brick. The clay has been formed by the decomposition of the limestone and consists of the insoluble residue after the removal by solution of the calcium and magnesium carbonates. The ice sheet which invaded the region and the water which resulted from its melting transferred and assorted this material, so that it no longer constitutes residual limestone clay in place, although in many localities a rather careful examination is necessary to prove that the material has been transported. In the process of removal and deposition considerable sand, pebbles, and boulders from distant points were mixed with the clay in different proportions. In some places these materials are so numerous that the clay can not be used, but in other places they are mainly concentrated at the base of the deposit and interfere very little with its utilization. The large cobbles and boulders distributed through the clay are picked out and discarded, but the small pebbles and sand are not especially objectionable when present in small amounts.

The clay deposits range in thickness from a thin layer to 60 feet, but in no place have they been worked to a greater depth than 30

feet. In most places the workable clay is only from 3 to 10 feet thick. A foot or two of surface loam which contains vegetable material is removed, and the clay is then worked downward to the underlying limestone. As the surface upon which the clay was deposited was very irregular, like that of limestone areas in general, the clay differs greatly in thickness in short distances, and pinnacles or loose blocks of limestone may come close to the surface in a pit where the clay averages 10 or more feet in thickness. This irregularity prevents the use of steam shovels in some places where they could otherwise be employed. Steam and electric shovels are used in some pits.

Though the glacial clays are particularly adapted to the manufacture of brick, they were long used also for making pottery and roof and stove tiles. In 1742 Lewis Huebner, who was a potter by trade, came to Bethlehem to erect a tile stove which he had made and soon afterward settled in the place. His plant was set up along Monocacy Creek a short distance north of Bethlehem, and he used clay found near by. The tile stoves, some of which were made almost entirely of tiles though others were made of tile and cast iron, were in use for many years. They were about 5 feet in height. M. S. Henry[67] gives the following description of the industry:

> Pottery, for many years carried on by Lewis Huebner, was a very lucrative trade in Bethlehem and in 1782 that business was rated at £ 130. It is said that the demand could not be supplied, more particularly in years when apples were plenty. Apple-butter boiling by the farmers was universal, and earthen crocks to preserve it were in great demand. Mr. Huebner also made the tiles for stoves, as well as the common tiles for the covering of houses, barns, and stables. For barns they were in use many years, and some of them may be seen to this day. When tile could not be had, farms and stables were thatched. Pipe heads were also made by Mr. Huebner in large quantities.

In the early settlement of the region bricks were made in many different places throughout the quadrangle where at the present time nothing remains to determine the location of the pits and kilns. The lack of easy transportation,—no railroads, canals, or improved roads,—caused many small brickyards to be opened for supplying local demand. With the improvement of transportation facilities the small plants have been closed, and the industry is now restricted to a few localities where large quantities of brick are manufactured. The present operating plants of the quadrangle are in northwest Allentown, a short distance south of Allentown, near Bingen and near Georgetown. Within recent years bricks have been made in Bethlehem, near Emaus, Hellertown, Catasauqua, and Nazareth.

[67] Henry, M. S., History of Lehigh Valley, p. 205, 1860.

C. C. Sensenbach operated a brickyard west of Aineyville in South Allentown from 1890 to 1913. The clay which contained few glacial boulders, was underlain by fine sand, some of which was mixed with the clay. The plant was operated from April to October each year and made daily 15,000 to 18,000 bricks.

On the south side of Little Lehigh Creek near the Eighth Street bridge in South Allentown Mr. Kichline made brick for more than 25 years. The clay, which contained very few pebbles, ranged in thickness from 4 to 11 feet. It was underlain by rotten limestone, which sometimes became mixed with the clay and caused the bricks to crack while burning.

The Ochs & Frey Brick Co. had two pits in operation near the south end of the Eighth Street bridge in South Allentown until about 8 years ago and now has one pit located about ¼ mile to the southwest, west of the Fairview Cemetery. The four kilns of this company had a combined capacity of 870,000 bricks. The clay in the old pits ranged in thickness from 2 to 12 feet and was overlain by about 6 inches of vegetable loam. A layer of gravel and sand separated the clay from the underlying limestone. In the present pit the clay ranges from 3 to 13 feet in thickness. An electric shovel is employed in the digging.

The Ed. G. Mattern brickyard, at Tenth and Tilghman streets, Allentown, was operated for about 60 years. The company ceased operations about 8 years ago and the site is now occupied by residences. In that time the clay was removed from a large area in northwest Allentown. The clay in most places ranges from 3 to 7 feet in thickness although in a few places it is 12 feet thick. The three kilns had a combined capacity of 500,000 bricks.

Frederick Bros.' brickyard at Fifteenth and Allen streets, Allentown, operates three kilns that have a combined capacity of 700,000 bricks. The clay formerly used was the ordinary residual type obtained from pits near the plant. It ranged from 3 to 12 feet in thickness, was overlain by a foot of loam and underlain by rotten limestone. The clay contained few glacial boulders. At present the clay used is being taken from an old mud-dam deposit located north of the fair grounds at 19th and Tilghman streets. The old iron mine which furnished the clay is now being filled. There are some layers of sand interbedded with the clay. The clay is dug by means of a steam shovel.

Swoyer Bros. Brick Co. plant, the largest in Allentown, is at Madison and Allen streets, Allentown. There are six kilns each of which has a capacity of 305,000 bricks, and the yard is well equipped with dryers and brick-making machinery. The clay ranges in thickness from 3 to 35 feet although at present clay exceeding 10 feet is seldom found. Pinnacles of limestone that rise nearly to the surface

were formerly considered as serious obstacles in the use of steam shovels, but for the past five years such shovels have been in successful operation. The only product is sand-faced red brick.

The largest and most recently built brick plant in the quadrangle, located about 1½ miles south of Allentown, belongs to the Lehigh Brick Co. The materials used are the residual and glacial clays that cover all the limestones of that section except along the streams. The clay, which varies in thickness from 6 to 20 feet, has been removed from a considerable area and eventually will be stripped from a large field. In places it is too sandy to use. Residual limestone masses and angular and rounded pebbles and glacial boulders up to 5 feet in diameter are abundant in places. The largest rocks are left in the pit, those several inches in diameter that have been loaded into the cars by the steam shovel are picked out by hand on the grizzlies, and the smaller pebbles are eliminated or crushed by the conical rolls.

The plant is well-equipped with a large stock house, belt conveyors, rotary dryer, centrifugal crusher, 8 round kilns with a capacity of 75,000 bricks each and 2 long continuous kilns with 22 openings each.

The combined annual output of the brickyards in and near Allentown is large but variable. These bricks are used locally and shipped to places along the lines of the Lehigh Valley R. R. and Central Railroad of New Jersey, especially to Newark, N. J. and to Scranton and Wilkes-Barre, Pa.

The Nazareth Brick Co. operates a plant about half a mile north of Georgetown. The clay contains numerous boulders from 1 to 2 feet in diameter that must be thrown aside. Lenses of sand and pebbles are present in parts of the pit and where numerous render the clay useless. The smaller pebbles are crushed in a Chilian mill, through which the clay is passed. The deposit occupied a basin in the limestone, and the rocks rise to the surface on all sides. It has a thickness of 60 feet, although it is worked only to a depth of 30 feet.

The plant of the Bingen Brick Co. on the Lehigh-Northampton county line, half a mile southwest of Bingen, long used the clay from an old mud-dam deposit from the Bahl limonite iron mine about three-eighths of a mile to the north. The deposit covers about 12 to 15 acres to a depth of 12 to 16 feet and includes the material deposited in two ponds, one on each side of Saucon Creek. The plant is on the south side of the creek, but clay is obtained from both sides. In recent years residual limestone clay has been used.

The material in the Bingen mud-dam deposits was more uniform and less sandy than that of most of the other mud-dam deposits of the region, although the section exposed in the pit showed strata of

somewhat different composition. The entire thickness of the deposit was dug, and when thoroughly mixed the clay was very tough. The composition of the clay was unlike that of most brick clays, as it was a mixture of ocher; red, white, blue, and black clays; shaly fragments of limonite ore; and some grains of quartz sand, all of which were washed from the limonite ore in the log washers. The prevailing opinion among iron-mine operators that such clays are useless seems to have been disproved at this plant as brick of fair quality were successfully made here for many years. They were much more porous than the brick made from the glacial clays described above and consequently were poorly adapted for outside use but entirely satisfactory for inner walls. Their porosity caused them to disintegrate under the action of frost on account of the amount of water which they absorbed.

The plant is well equipped and operates four kilns, each of which has a capacity of 180,000 bricks. Except for two or three months during the winter the plant is in continuous operation.

There is little doubt that many other mud-dam deposits throughout the region might be equally serviceable for the manufacture of brick, although few are so favorably situated as the Bingen deposit, which was directly along the line of the Philadelphia & Reading Railroad between Philadelphia and Bethlehem. Almost every old limonite mine has a mud-dam deposit nearby, where the waste material from the ore was carried. Although the clays associated with the limonite ore are of many different kinds the following analyses are fairly characteristic. Analyses 1 and 2 were made by J. M. Stinson[68] and 3 and 4 were made by J. W. Shimer.

Analyses of clays associated with limonite ore in the Allentown quadrangle, Pa.

	1	2	3	4
Silica	53.170	49.130	72.16	64.55
Alumina	24.431	33.873	21.76	22.77
Ferric oxide	5.400	3.040	.99	5.63
Lime	.130	.120	.22	.40
Magnesia	3.376	.987	.69	1.28
Soda	1.228	.526	2.12	2.80
Potash	7.155	.634	3.02	3.25
Titanic acid	1.250	.190	------	------
Water	4.860	11.500	4.75	4.67

1. Clay found inside an orebomb, Schneider's mine, 3 miles southwest of Friedensville.
2. Clay from Wharton mine, 2 miles southeast of Hellertown.
3. White clay from Wharton mine, 2 miles southeast of Hellertown.
4. Yellow clay from Wharton mine, 2 miles southeast of Hellertown.

In the manufacture of Portland cement some of the companies near Nazareth at times find it necessary to add some clay to the rock used, which runs too high in lime. Elsewhere in the cement region the cement rock is almost invariably too low in lime. At the plants of the Dexter Portland Cement Co. and the Nazareth Cement Co. some

[68] Pennsylvania Second Geol. Survey, Rept. MM, p. 268, 1879.

of the glacial and residual limestone clay that lies at the surface, such as is used elsewhere for the manufacture of brick, is added when necessary. The amount needed, however, is small and is obtained nearby. The Nazareth Cement Co. formerly worked a small pit near the mill, which is shown on the map (Plate 11).

MINERAL PIGMENTS.

For many years the mining and preparation of mineral pigments has been an active industry in this part of Pennsylvania, and at the present time several paint companies have headquarters in Allentown, Bethlehem, and Easton. Naturally the bulk of raw materials used comes from other regions, as each plant requires a great variety of materials, such as no one district produces. The paint industry of the region, however, owes its development to the local occurrence of ocher, umber, and black shales, which have long been mined.

Ocher.—Ocher, which is a mixture of clay and limonite, is almost invariably associated with the limonite iron ores that have been so extensively worked in different parts of the quadrangle. During the active operation of the iron mines the better grades of ocher were frequently taken out separately, washed, and marketed for paint. This was the beginning of the present paint industry of the region. Some years ago paint mills which used local ores almost entirely were operated just west of Pine Top and also near Bingen. The plant of Henry Erwin & Sons, first known as the Blue Mountain Paint Mills, began operations at the present site along Monocacy Creek just north of Bethlehem in 1868.

The ocher as mined contains numerous hard particles of limonite and quartz, which are removed by mixing thoroughly with water in a log washer and then passing the material into a series of troughs in which the overflow at the end of one trough passes into the next trough, carrying only the finest materials in suspension near the surface. The first trough collects the coarsest particles which have dropped out of suspension, and each succeeding trough receives finer sediment. The water with the suspended particles of ocher in some plants is passed through as many as 26 troughs, each 16 feet in length, and the sediment collected in all the troughs is thrown away. The water then is carried to a large pond, where after the sediment has settled the water that is practically free from suspended particles of ocher is permitted to flow away. When the basin is filled with sediment it is permitted to dry to the consistency of putty by exposure to the sun and then dug by shovels and put in wheelbarrows to be taken to dry sheds. In these sheds, where it is protected from rain, the ocher at some plants is air dried and at other plants is dried by steam, which passes in pipes beneath the racks on which the ocher is laid. After thorough drying the ocher is pulverized in mills and bagged for shipment.

In most places no attention was paid to the ocher while the mines were in operation, and everything brought to the surface—iron ore, ocher, and different kinds of white, red, and black clays—was put into the log washers. The coarse ore was saved, and the water carrying all the finer materials in suspension was carried through troughs to large ponds made by earthen dams. These ponds for the collection of sediments were necessary in order to avoid the obstruction of the streams into which the waste water flowed. While the iron mines were being worked these deposits of mud were regarded as worthless, but in recent years a number of them have been found to contain some fairly good washed ocher. At certain times all the material washed from the ore was highly colored, and these layers when thick enough can be readily separated from the beds that are more sandy or less highly colored with limonite. The sediment deposited near the place where the water entered the pond invariably contains too many coarse particles to be of value for paint, but at the sides of the pond farthest away from the mine only the finest sediments were deposited and washed ocher of fine quality can be obtained there in some deposits.

Within the quadrangle at the present time no ocher or limonite iron ore is being mined nor is any ocher being obtained from mud-dam deposits. Both east and west of the quadrangle, however, ocher of both kinds is being worked, the occurrences being similar to those prevailing within the quadrangle. It is probable that some of the iron ore deposits along the base of the mountain northeast of Emaus, as well as those in the limestone valleys which, when formerly worked, yielded considerable marketable ocher, might be found to contain equally as good material as that now obtained in nearby regions. The demand for this material, however, is not great enough to justify the necessary investigations. The amount of mud-dam material required is also small, and consequently there is no necessity for examining these deposits, even though this work could be done rather easily by shallow excavations. Scores of these mud-dam deposits are present in the region, for a settling pond was built near almost every limonite mine operated.

The following analyses of materials from adjoining quadrangles are characteristic of the ochers and mud-dam deposits that are mined:

Analyses of ochers from Topton and Easton, Pa.

[Furnished by Henry Erwin & Sons.]

	1	2	3
SiO_2	55.50	58.50	39.70
Al_2O_3	18.66	20.15	12.36
Fe_2O_3	17.49	15.25	37.64
MgO	-----	-----	1.37
Combined water	8.35	6.10	7.83

1. Best grade of ocher from Topton.
2. Second quality of ocher from Topton.
3. Ocher from mine of A. K. S. Sampson, South Easton.

Analysis of mud-dam deposits 1¼ miles northeast of Breinigsville, Pa.[69]
(A. S. McCreath, Analyst.)

Silica	60.53
Alumina	17.40
Ferric oxide	9.29
Lime	.08
Magnesia	1.92
Water	5.51
Alkalies (by loss)	5.27

Umber.—Much of the ocher of the region contains small amounts of manganese oxide and almost every analysis of limonite iron ore shows its presence. Under these conditions it seems rather strange that in few localities is the percentage of manganese great enough for the mixture to be called umber.

On the south slope of Quaker Hill, or Camel's Hump, about 2½ miles north of Bethlehem, there is a deposit of umber that was formerly worked by Henry Erwin & Sons and later by C. K. Williams & Co. The deposit was worked in a small way for more than 25 years. It was worked in shallow open pits and shafts. The following section at one side of the main pit is typical, although a different arrangement of the materials may be found 10 feet distant.

Section in umber pit of C. K. Williams & Co., 2½ miles north of Bethlehem, Pa.

	Feet
Soil and hillside wash	3
Reddish-brown clay	1½
Light-yellow ocherous clay	5
Darker-yellow ocherous clay	½
Dark-brown umber (base not exposed)	6
	16

In one place a pit was sunk to the depth of 48 feet, but in most places the umber does not extend that far. White and yellow clay is said to lie beneath the umber bed.

In the layer of hillside wash there are many angular pieces of gneiss that have been washed from the small hill of gneiss that lies to the north and that has reached its present position by a strike fault along the north side of the hill. Within the bed of umber there are a few layers and pockets of yellow ocher, some of which are as much as 14 inches in thickness. The umber bed further contains many small pieces of vein quartz, fragments of iron ore, and limonite geodes filled with drab clay. These impurities are more abundant in the upper portion.

The umber and associated materials represent the decomposition and replacement products of the Hardyston quartzite, which extends

[69]Pennsylvania Second Geol. Survey, Rep. D, p. 33 1875.

along the south flank of the hill, as shown by the float rock. The umber deposit also contains some pieces of the quartzite that have resisted decomposition.

The umber was shipped to Easton, where it was washed and ground. The finished material commanded a price of $18 to $20 a ton.

A short distance east of these workings a shaft was sunk several years ago, and there are several tons of umber lying near the caved shaft. Though the color is good the large amount of grit present is objectionable.

Plate XIV. Witte umber pit, 2 miles northeast of Springtown, Pa.

Near the eastern edge of the Allentown quadrangle about two miles northeast of Springtown, Henry Erwin and Sons, in recent years, have obtained some umber of fair quality from the farm of W. F. Witte. The material is taken from an open pit that was opened for mining limonite iron ore which proved too lean to be profitable. Occasional masses of iron ore of good quality were encountered but the amount was small. A large quantity of iron ore was mined by open cuts and by shafts in the region a short distance to the west (Mine No. 133 described on an earlier page).

Umber and ocher were found in the iron mines but in general little attention was given to them although it is said that some was dug and burned in kilns nearby. It was difficult to secure a market for the product and the industry was abandoned. Iron mining was begun in 1853 and continued for many years.

The umber in the pit now about to be reopened, after remaining idle since 1918, lies in a bed that is exposed to a depth of about 8 feet. It may be thicker. It has an overburden of about 20 feet of hillside wash and residual clay. The umber is more uniform than in most deposits and contains little foreign matter other than occasional small masses of limonite.

The umber owes its origin to the replacement of siliceous sandstones and quartzites near the contact of the overlying limestones. Pieces of the unreplaced rock are present in the umber.

A partial analysis that is probably approximately correct, although the analyst is not known, is as follows:

Analysis of umber northeast of Springtown.

	Per cent
Fe_2O_3	40.00
MnO_2	5.00
SiO_2	25.00
Al_2O_3	10.00

A photograph of the pit when in operation about 6 to 8 years ago is given on page 156.

Black shales.—In the vicinity of Nazareth some very black carbonaceous shales were for many years used in the manufacture of black paint. Rogers[70] says:

In the neighborhood of Nazareth, which is on the line dividing the Slate from the Limestone formation, a material is procured, which answers the ordinary purposes of black paint. This appears to be simply a more than usually carbonaceous, black and soft variety of the slate, occurring near the base of the formation a little above its contact with the Limestone * * * *. It requires to be ground in a dry mill, and levigated in troughs by passing over it a stream of water. Thus prepared, it constitutes, when mixed with oil, a very excellent pigment for the exterior of houses, fences and other structures exposed to the weather.

A traveler in that region in 1799 reports the use of the same material, so it would seem that these slates were quarried for paint for many years.

On our return to Nazareth we saw two men searching for coal. They had penetrated to the depth of 12 feet, and were flushed with sanguine expectations of success.

They were prompted to this search by the opinion of a person who had passed this way not long before and was acquainted with the coal mines of Europe.

The steward had taken from the side of the hill, near this place, a saponaceous black earth, which he had ground and mixed with oil and used as paint. It appears as well and as durable as any other colour. He has by experiments altered the first appearance of black, and made samples of other colours with it.[71]

A little of the refuse slate from the slate quarries has been ground and used for paint.

[70] Rogers, H. D., Second annual report on the geological exploration of the State of Pennsylvania, p. 35, 1838.

[71] Ogden, J. C., Excursion into Bethlehem and Nazareth, in Pennsylvania, in the year 1799, Philadelphia, 1805.

PYRITE.

In the discussion of the origin of the limonite (p. 44) attention was called to the large amount of pyrite which has been found in the lower workings of these ores, and an explanation of its origin was given. Pyrite has probably not been more generally noted in the mines because the amount of water struck in the lower levels caused the mines to be abandoned before the pyrite was reached. H. M. Chance[72] and Charles Catlett[73] have ably described the occurrence of pyrite in association with limonite in the Appalachian region and have discussed the problem of its origin.

It seems probable that the limonite of the Cambrian quartzite and part of that of the limestone regions of the Allentown quadrangle has been formed by the oxidation of pyrite that was precipitated from solution in ascending waters. If this theory of the origin of the limonite ores is correct deposits of pyrite must be widespread in the region.

Crystals or rounded concretions of pyrite are common in all the rocks of the quadrangle, but in only a few places have deposits of possible commercial value been found. Though some pyrite has been marketed it has all been obtained from mines that were worked primarily for iron ore. The promising deposits are so unlike that they must be described separately.

The largest known deposit of pyrite in the Allentown quadrangle is about 2 miles northeast of Emaus, on the northwest slope of South Mountain. It occurs in the deepest working of one of the numerous limonite mines that form an almost continuous line for about 3 miles along this slope of the mountain. The pyrite has been deposited by replacement of the quartzite, and specimens can be obtained that range from practically pure pyrite through pyritic quartzite to quartzite in which no pyrite can be detected. The pyrite is granular, and, as determined by Chance, the grains "are generally small enough to pass through a 20 or 30 mesh screen; a large portion passes through an 80-mesh screen, and a considerable percentage is of still finer texture." No data are available regarding the exact occurrence of the pyrite ore, but it probably forms layers or lenses of variable thickness interbedded with nonpyritiferous quartzites.

For a few years there was some extensive core drilling in the vicinity of this mine, and some shafts were also sunk. Although detailed reports are not available, it is said that considerable pyrite was found but the project was abandoned because of the expense of pumping the enormous quantity of water that was en-

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[72] Am. Inst. Min. Eng. Trans. vol. 39, pp. 522-539, 1908.
[73] Idem, pp. 916-920.

countered and also because of the difficulty of keeping the shaft open on account of the clay and loose rock in the upper part, which tended to move slowly downhill.

The depth at which the deposits of pyrite are found depends almost altogether upon the configuration of the region. In regions where the water level is high and erosion is relatively rapid much pyrite may be expected at a depth of 100 feet or perhaps less. In most places, however, pyrite in workable quantities would not be reached at less than 150 to 200 feet below the surface.

In regard to the pyrite that underlies the deposits of the mountain ores the available information seems to indicate that the supply is abundant but at present of doubtful value.

In the limestone regions pyrite has been found in large quantities in the Friedensville zinc mines (see p. 76). When the mines were worked the sulphide ores were less favored than the oxidized ores and in some of the mines the sulphides were left. These ores consist mainly of pyrite but contain more or less sphalerite. It seems probable that some of these ores which are too low in zinc to be considered zinc ores may be of value on account of the pyrite.

In the limonite iron mine three-quarters of a mile northeast of Lanark considerable pyrite was found in the lower levels, and had work continued no doubt much more would have been revealed. The mine was compelled to close when pumping ceased at the zinc mines, as the amount of pumping required for the drainage of the iron mine was too great for successful operation. Next to the Friedensville zinc mines this locality is regarded as the most promising place for pyrite ore in the limestone areas of the quadrangle. At Breinigsville, about 9 miles west of Emaus, considerable pyrite was mined some years ago.

Chance believes that the pyrite found in the limestone was contained originally in overlying shales and has reached its present position by the collapse of caverns in the underlying limestones. The occurrence of the pyrite in the Friedensville zinc mines seems to disprove this hypothesis. As explained more fully in the discussion of the origin of those ores, ascending waters unquestionably have deposited the pyrite and sphalerite through replacement of certain limestone strata and the filling of open fissures, and deposits of pyrite in the limestone areas probably originated in the same way.

The economic importance of the deposits of pyrite in the limestone regions has not been determined. Though no doubt there are large amounts in many places beneath the deposits of limonite the drainage of deep mines in the limestone valleys would be a very serious obstacle and would prevent many, perhaps all, from being worked with profit. The deposits are formed along well-de-

veloped watercourses, and the amount of water that entered many of the old limonite mines when a depth of 50 feet or more was reached was so great that the cost of pumping was very high. Although good pyrite ore may be found locally at depths less than 50 feet, in most places it has been largely oxidized to limonite to a considerably greater depth. Little pyrite ore would probably be found less than 100 feet from the surface, and at such depths much water would be found.

Pyrite is also prominent in the Backenstoe graphite mine, described below. Many of the specimens on the dump indicate a fairly good pyrite ore, but no definite information is available in regard to the occurrence and general average analysis of the rock.

GRAPHITE.

Graphite-bearing rocks are found in several places in the Allentown quadrangle, but in most localities the amount of graphite is so small that it is likely to be overlooked. In three places, however, there is a noticeable amount of graphite, and in two of these places considerable development work has been done, although, so far as known, no attempt to concentrate the graphite has ever been made.

Similar deposits of graphite have been worked in several places in Berks and Chester counties, some of them successfully but most of them at a loss. The failures have been due mainly to the difficulties of concentration on account of biotite and other minerals intimately associated with the graphite, the tendency to overcapitalization, the inability to procure sufficient water for concentration, and the uncertainties of the market owing to competition with foreign graphite and the conservative attitude of graphite users. Nevertheless a few graphite properties in Pennsylvania have been profitably operated.

The Backenstoe graphite mine is about 1 mile east of Vera Cruz station and 1 mile west of Limeport, on the north side of the road that connects the two places. The history of the mine is somewhat indefinite, but information obtained from different sources indicates that it was first opened more than 50 years ago as a gold and pyrite mine. The large amount of pyrite in the graphite ore probably contains traces of gold. It is said that many men in the vicinity lost money in the venture.

Between 1890 and 1900 it was reopened as a graphite mine and work was carried on for about two months. A few years ago the property was purchased by the Schuylkill Stone Co., of Philadelphia, and the tunnel was again cleaned out, but no further work was done. The development work consists of a shaft about 35 feet deep, located near the top of the hill, and a tunnel about 150 feet long that extends into the hill at a lower level. There are no exposures of the graphite rock near the mine, and the shaft and tunnel could not

be entered. The loose pieces of rock obtained from the tunnel and shaft, however, probably represent the true character of the rock fairly well.

The rock is a graphitic gneiss, composed mainly of kaolinized orthoclase, together with some perthite, white quartz, pyrite, graphite, biotite, hornblende, and an asbestiform mineral. Many specimens show a distinct augen or lens structure, the pyrite especially occurring in small lenses about one-half inch in diameter, around which the graphite flakes are curved. The graphite flakes are friable, probably owing to weathering, and some of the graphite even appears to be amorphous. Many of the larger flakes are iridescent. Much of the rock seems to have been sheared, and the flakes of graphite overlap, forming bands or streaks of the matted flakes which extend through the rock. Pegmatites are present and contain large flakes of graphite that are irregularly disseminated throughout the rock. It is doubtful whether the mine would yield a good quality of graphite flake. Biotite, though relatively abundant in some specimens, is practically absent in most of the rock and would not be a serious handicap. Nothing is known of the thickness and extent of the graphite-bearing bed.

On the farm of John Wright, 1 mile east of Emaus, on the top of South Mountain, some prospect pits were dug about 18 years ago. No information is now available concerning the amount of work done, the structure of the rock, and the thickness of the graphite-bearing bed. No outcrops of the graphitic gneiss could be found in the immediate vicinity of the pits.

The rock in which the graphite occurs is an acidic gneiss that contains both plagioclase and othoclase, the plagioclase predominant, blue quartz, considerable pyrite in small isolated grains, graphite, and biotite. The plagioclase is greenish-gray. The gneiss is indistinctly banded, and the graphite flakes show little indication of parallelism of arrangement. In some of the rock the flakes of graphite cut into each other. The flakes are of fair size, the largest one-half inch in diameter, and are tough and bright; some of them are iridescent. The presence of the biotite is said to have discouraged the men who were engaged in prospecting the property, and operations were discontinued.

Across the road to the east, on an adjoining farm, a prospect pit was also dug, but it has now been filled and only a few pieces of the weathered rock remain about the opening. These fragments seem to be similar to the rock on the John Wright farm.

Recently, in the operation of a limestone quarry in the pre-Cambrian crystalline limestone along the west side of Monocacy Creek directly west of Pine Top, a band of promising graphite schist was uncovered. The quantity available, however, seems to be small. The limestone also contains numerous flakes of lustrous graphite.

MICA.

Pegmatite dikes occur in many places in the gneisses of the Allentown quadrangle, but most of them contain very little mica. A few, however, show much fairly coarse-grained muscovite. One of these dikes, about 1½ miles southwest of Seidersville, was prospected in 1883 by the sinking of two shafts. Some crystals were found that produced sheets from 3 to 4 inches in width, but they were not numerous enough to make the project profitable. The muscovite was considerably clouded by included impurities.

PEAT.

The deposits left by the ice sheet interfered less with the drainage in this area than in most other glaciated areas of the country. As a result postglacial peat bogs formed by the filling of ponds and swamps along the courses of the streams are rare. The only large bog in the quadrangle is on the north side of Quaker Hill about 3 miles north of Bethlehem. (See Pl. XV). The glacial débris which dammed Monocacy Creek, produced a shallow pond that was gradually filled with a growth of vegetable matter, consisting largely of sedges and grasses. It is known as the Detweiler peat deposit and first attracted attention about 70 years ago, when during a dry summer it was ignited and burned for several months. It was investigated about 25 years ago with the intention of utilizing the material as a nonconductor for heat in the manufacture of refrigerators and possibly for fuel. In the refrigerators the space between the exterior wooden box and the lining of galvanized iron or porcelain was to be filled with peat.

The deposit covers about 2 acres on the south side of Monocacy Creek, which at this place flows in a westerly direction. A small stream, fed mainly by the Camel's Hump spring, flows westward through the deposit and joins the Monocacy.

The following section shows the character of the deposit near the south side of the area.

Section of Detweiler peat deposit, 3 miles north of Bethlehem, Pa.

	Ft.	In.
Peat varying in color from dark brown at the top to black at the bottom	4	7
Water-deposited clay	1	2
Glacial till	..	10
Decomposed gneiss		

In the northern part of the area the underlying rock is Ordovician limestone of Beekmantown age.

Plate XV. Detweiler peat deposit near Quaker Hill, 3 miles north of Bethlehem, Pa.

Analyses of two samples each from the top (1 and 2), middle (3 and 4), and bottom (5 and 6) of the peat layer gave the following results:

Analyses of peat from Detweiler deposit near Bethlehem, Pa.

[J. T. Callaghan, Jr., Analyst.]

	1	2	3	4	5	6
Moisture	12.06	12.37	14.71	10.31	10.06	9.82
Volatile matter	47.31	46.93	44.74	50.13	37.65	38.64
Fixed carbon	25.17	25.46	25.70	23.79	29.45	28.47
Ash	15.46	15.24	14.82	15.67	22.84	23.07

The high ash content of samples 5 and 6 is caused by the clay mixed with the samples.

The peat ignited readily and burned for a few minutes with a flame and later with a dull glow. In the first stages of burning it produced a disagreeable odor.

SOILS.

The soils of Lehigh County have been studied in detail, and a map showing the distribution of the different types has been prepared by the Bureau of Soils.[74] The area mapped comprises about

[74] Carter, W. T., Jr., and Kerr, J. A., Soil survey of Lehigh County, Pa.: U. S. Dept. Agr., Bur. Soils, Field Operations, 1912, pp. 109-153, map, 1914.

one-third of the Allentown quadrangle. The map shows 32 different soil types, and 23 of them appear in the part of Lehigh County that is included in the Allentown quadrangle. In the absence of any detailed map of the greater part of the quadrangle the soils will be discussed in connection with the different kinds of rocks from which they have been produced, and only the more widespread soils will be described.

Ordovican shales and slates.—The belt of dark-colored shales and slates that underlies the northwestern portion of the quadrangle, north of a line drawn from Nazareth through Bath to Siegfried, is marked by soils that show little variation. The type known as the Berks shale loam is the most abundant in the area and is described by Carter and Kerr[75] as follows:

The soil of the Berks shale loam is a light-brown to yellowish-brown silt loam about 8 inches deep. The subsoil is a yellow silty clay loam which grades downward into a yellow friable silty clay. Large quantities of shale or weathered slate chips, with some fragments several inches in width, are scattered over the surface and disseminated throughout the soil section. The shale fragments are soft and easily broken, and where cultivation has been carried on for many years they have been reduced to small particles. A mass of weathered shale is generally encountered within 24 inches of the surface. On some of the slopes this shaly layer occurs at a depth of 8 or 12 inches, while in the comparatively inextensive level areas it may not be reached at less than 30 to 36 inches. The weathered fragments vary from yellow or grayish yellow to olive or brown, while the less weathered fragments of the substratum are more bluish black in color.

On many of the higher ridges irregular and flat sandstone fragments a few inches across are often encountered on the surface and throughout the soil section. * * * In some places numerous fragments of quartz are found on the surface. * * *

The drainage throughout the type is good. Owing to the slope, water does not stand on the surface, while the shale fragments in the soil and subsoil permit the rapid percolation of soil water. Where the subsoil is a mass of shale fragments, as it is throughout a large part of the type, the soil is droughty, and crops suffer during dry seasons. Where the shale has weathered more deeply the droughty nature of the soil is less marked. With moderate care the surface does not erode badly, and few of the farms include gullied slopes. This is doubtless due to the fact that the mass of small shale fragments keeps the soil from washing badly, except under very adverse conditions.

A large part of this type is in cultivation, though many small areas are still forested with the original growth of chestnut and oak. In the timbered areas the surface soil has a more yellowish color, but after cultivation it becomes darker.

The type is well adapted to general farming, and during favorable seasons good yields are secured. In very dry seasons the yields are low. Consequently crop yields vary considerably, depending on the rainfall. The productiveness of the soil depends largely on its depth. On the steep slopes and tops of the sharper ridges, where the shale mass is near the surface, the crop yields are much lower and less certain than on the gentler slopes and gently rolling tops of broad ridges, where the soil is deeper. * * The land is easily cultivated under all conditions of moisture, and since it warms up quickly and responds readily to good treatment, it is considered desirable land. The farm implements and buildings indicate a general condition of prosperity.

The general farm crops are grown on this soil, though a specialty is made of producing Irish potatoes, to which the soil is particularly adapted. Individual plantings of this crop range from a few acres to 40 or 50 acres. The potatoes are grown largely in conjunction with other general crops. By the liberal use of stable manure and commercial fertilizers 200 to 250 bushels per acre of potatoes of excellent quality are produced. Some farmers, however, do not use commercial fertilizer but get good results with applications of barnyard manure. Corn pro-

[75] Idem, pp. 141-142.

duces 20 to 70 bushels, wheat 15 to 30 bushels, oats 20 to 50 bushels, rye 15 to 25 bushels, and hay 1 ton to 1½ tons per acre. In some of the more rolling sections little wheat is grown on this type, and rye takes its place to a large extent. Oats do well only on the deeper phases of the soil in good seasons. In dry seasons, in areas where the shale is near the surface, the yield is very light. There are some excellent fields of alfalfa on the type. About three cuttings per year are secured, with a yield of one-half ton to a ton per cutting. Some buckwheat is grown, with fair results.

Limestone valleys.—Throughout the limestone valleys the soils are brown to reddish-brown and consist of loam and clay derived from the underlying limestones with the addition of carbonaceous material from decayed vegetation. The soil differs greatly in thickness in different localities. On level uplands the limestone comes to the surface in places, but elsewhere it is deeply buried. Though the soils that overlie the limestones mainly represent the insoluble material left after the soluble material in the limestones has been removed by solution, yet the soil is not strictly residual, for it has been disturbed by the glacial ice sheet that once passed over this area. The glacier introduced much foreign material, consisting of well-rounded pebbles, cobbles, and boulders of fine sandstones and quartzites, which in places are so numerous that they must be gathered from the soil. Large piles of these boulders can be seen in many places along the fences dividing the fields. Though these stones are numerous enough in certain regions to require their removal they are almost entirely absent in many places.

The soil type most widely distributed in the limestone valleys is the Hagerstown loam, as described in the report on the soil survey of Lehigh County.[76] Its adaptabilities are given as follows:—

The Hagerstown loam is utilized almost entirely for general farming. It is considered the strongest and most productive upland soil in the county, and the general farm improvements indicate that it is the most valuable type. The original forest growth, consisting largely of white oak, has been cleared away, and practically all of the land is cultivated. The principal crops grown are corn, oats, wheat, some hay, and in certain sections potatoes. Dairying is also practiced to some extent. Corn produces 40 to 90 bushels per acre, averaging 50 to 60 bushels, oats 30 to 60 bushels, with an average of about 50 bushels, and wheat 20 to 35 bushels, probably averaging about 25 bushels per acre. From 1½ to 2 tons of hay per acre are produced. Rye is grown to a slight extent, yields ranging from 15 to 25 bushels per acre. Potatoes are grown for market in some sections and produce with fertilization 150 to 250 bushels and possibly more per acre. A small amount of alfalfa is grown, producing one-half ton to a ton per cutting, with three cuttings a season.

Cambrian quartzite and pre-Cambrian gneisses.—The report on the soil survey of Lehigh County differentiates the soils of the quartzite and gneisses into several types, all of which are, however, decidedly stony and only locally suited for cultivation. The type designated Chester stony loam is the most common and is fairly characteristic of all the soils formed from these rocks. It is described as follows:[77]

The Chester stony loam is a brown or yellowish-brown loam or heavy loam, underlain at a depth of 5 to 8 inches by a yellow gritty clay loam or crumbly clay. In some places the soil is sandy or decidedly gritty. The subsoil occasionally has

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[76] Carter, W. T., Jr., and Kerr, J. A., op. cit., pp. 136-137.
[77] Idem, pp. 126-127.

a slight reddish tinge, and in places it is reddish yellow. Fragments of the gneiss and granite parent rock, together with fragments of quartzite from associated beds, are present on the surface and in the soil body in amounts sufficiently large to give the soil a decidedly stony character. On the steeper slopes the parent bedrock is near the surface. Ordinarily the land can not be satisfactorily cultivated until many of the stones are removed. Masses of rocks several feet in diameter are often encountered in the forested areas and occasionally in cultivated fields.* * *

The topography of this type is hilly to broken, and in many places the slopes are very steep and stony, in some cases being too steep for cultivation. Drainage is good throughout all parts of the Chester stony loam. The soil is fairly retentive of moisture.

The greater part of the type is forested with chestnut and oak, with some birch, hickory, and poplar. However, some of it has been cleared of timber and the larger stones, so that the land can be cultivated.* * * This land could probably be utilized to better advantage for fruit, especially apples, than for the production of farm crops.

Triassic conglomerates.—The hill between Spring Valley and Fairmount, included within Lehigh, Northampton, and Bucks counties, and a small area at the edge of the quadrangle southeast of Limeport possess types of soil distinct from any other found in the quadrangle. The principal soil type is called the Penn stony loam, which is described as follows in the report on the soil survey of Lehigh County:[78]

The surface soil of the Penn stony loam to an average depth of about 8 inches is an Indian-red mellow silt loam. The subsoil is an Indian-red clay. Sandstone and some light-colored quartzite fragments are present in quantities sufficient to interfere with cutivation. Many of the sandstone fragments have an Indian-red color. The stones on the surface are generally small, being less than 2 inches in diameter, but some of the fragments are several inches through. In preparing the land for cultivation many of these stones have been removed and piled along the fences. * * *

The Penn stony loam is well drained, and notwithstanding the steep slopes it does not suffer from erosion.

A large part of the type is in cultivation, though the greater part of the larger area in the extreme southeastern corner of the county remains forested with chestnut and oak. The land from which the larger stones have been removed is quite productive, and good yields of the general farm crops are secured. Corn produces 20 to 50 bushels, oats 20 to 40 bushels, wheat 12 to 20 bushels, and timothy and clover about 1 ton per acre. The yields are slightly better on the less stony soil, where the land has been put in a good state of cultivation.

The soil is adapted to peaches, and there are some good orchards on the type which give excellent results. The trees are not injured by frost, being on the high ridges. Apples, plums, pears, cherries, small fruits, and berries do fairly well.

Triassic shales.—The Triassic shales of the southeastern corner of the quadrangle produce soils that are mainly red but in places brown, depending upon the character of the rocks from which they have been derived. In the report on the soil survey of Lehigh County the most abundant soil of these shales in the Allentown quadrangle is called the Penn shale loam and is described as follows:[79]

The surface soil of Penn shale loam is an Indian-red to chocolate-brown silt loam, extending to an average depth of about 8 inches. The subsoil is an Indian-red clay or silty clay loam which quickly grades into silty clay. Small fragments of

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[78] Idem, p. 130.
[79] Idem, pp. 130-131.

Triassic shale are abundant over the surface and throughout the soil. In some places bedrock of an Indian-red shale is encountered within the 3-foot section. On the steeper slopes the rock is near the surface, but on the more gentle slopes it may not be encountered, though the lower subsoil is often a mass of weathered shale fragments. As a rule the shale content increases with depth. The soil is easily cultivated, except when quite wet. Clods sometimes form, but may be broken without difficulty. * * *

The type has an undulating to rolling topography and is dissected by a number of small streams. The slopes are gentle to fairly steep. Surface drainage is good, and erosion sometimes occurs, but where care is taken in the management of the soil this is not excessive. The soil is quite droughty, as the shale material makes a porous subsoil which permits the rapid percolation of water. Consequently in seasons of dry weather crops suffer greatly on this type. In years of normal rainfall good yields are secured.

The Penn shale loam is a productive soil, and practically all the type is cultivated. It is devoted to the staple crops of the section, including corn, oats, wheat, rye, timothy, clover, and some potatoes. In favorable seasons corn produces 30 to 60 bushels, potatoes 100 to 150 bushels, oats 30 to 50 bushels, wheat 15 to 20 bushels, and hay 1 ton to 1½ tons per acre. Apples, peaches, and small fruits do well on this soil. The type is well adapted to the production of vegetables, which are grown in home gardens for local use.

Alluvial soils.—Along Lehigh River there are several areas of alluvial soils called the Schuylkill fine sandy loam in the report on the soil survey of Lehigh County. The type is described as follows:[80]

The surface soil of the Schuylkill fine sandy loam is a brown to black fine sandy loam. It is 10 to 14 inches deep and contains a high percentage of fine coal particles, brought from the coal fields by the Lehigh River. The subsoil is a brown to buff friable fine sandy loam to fine sandy clay. Near the river the coal particles are present in the soil and subsoil in quantities sufficient to give the soil a black color and a light, fluffy feel. Farther back from the stream the coal particles are not abundant in some places, and the color of the soil and subsoil is brown. * * * It occupies very narrow strips of first-bottom lands along the Lehigh River and a number of small islands.

All of the type is subject to overflow, being only a few feet above the river at normal stages. This type constitutes practically all of the first-bottom or overflow land along the Lehigh River, and owes its origin to sediment deposited by that stream. * * *

The surface is level, but drainage is good, as the soil material is underlain by beds of gravel which permit the rapid downward movement of soil water. Overflows are common but seldom occur during crop seasons. * * *

Corn, oats, and wheat are grown, but the greater part of the type is utilized for truck farming. All kinds of vegetables are grown with success, and the general farm crops give fair returns. Apples do well on the type where the coal particles are not abundant. The productiveness of the land seems to be proportional to the amount of coal particles present, those areas in which the soil is composed almost entirely of this material being very poor. Where little of the coal is present the land is quite productive, and is especially adapted to vegetables.

Triassic diabase.—In the southeast corner of the quadrangle are small areas of Triassic diabase that furnish typical soils. The soil is thin and consists of a rather impervious clay in which are numerous large rounded boulders of disintegration. The soils are poorly drained, and for this reason and also because of the presence of so many boulders few of these areas are cultivated. They are mainly covered with forest.

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[80] Idem, p. 147.

WATER RESOURCES.

SURFACE WATERS.

Stream Flow.

A record of the flow of Lehigh River at Bethlehem has been obtained in cooperation with the Water Supply Commission of Pennsylvania and the Civil Engineering School of Lehigh University during the periods September 22, 1902, to February 13, 1905, and April 26, 1909, to September 30, 1914. The gaging station is at the New Street Bridge, which connects Bethlehem and South Bethlehem.

The following table shows the discharge in second-feet for each complete month and year and the maximum and minimum days during each period or year.

Monthly discharge in second-feet of Lehigh River at Bethlehem, for 1902-1905 and 1909-1914.

[Drainage area, 1,235 square miles.]

Month	1902	1903	1904	1905	1909	1910	1911	1912	1913	1914
January	--------	2,990	1,940	3,750	--------	2,820	2,680	1,590	4,390	1,880
February	--------	4,160	2,220	--------	--------	2,520	1,350	1,920	1,640	2,360
March	--------	5,590	5,040	--------	--------	4,550	1,890	5,400	5,200	3,220
April	--------	4,300	3,270	--------	--------	3,720	3,220	4,390	5,240	4,130
May	--------	1,200	1,240	--------	3,360	2,700	1,220	2,850	2,800	2,540
June	--------	1,960	1,600	--------	1,410	2,040	2,440	1,000	1,110	895
July	--------	1,970	1,270	--------	785	704	909	572	731	1,520
August	--------	2,070	1,110	--------	478	428	1,180	698	538	981
September	--------	1,590	1,080	--------	444	512	2,210	1,320	633	492
October	4,810	3,720	1,730	--------	424	308	3,110	1,710	1,420	--------
November	1,940	1,330	1,500	--------	370	629	2,240	2,200	2,180	--------
December	4,710	1,870	1,320	--------	1,170	749	2,230	2,340	1,930	--------
The year	--------	2,720	1,950	--------	--------	1,800	2,060	2,170	2,320	--------
Maximum day	26,800	25,800	20,000	--------	9,540	28,400	9,880	21,900	27,500	10,900
Minimum day	1,100	605	685	--------	250	160	384	321	349	293

Water Power.

The streams of the quadrangle furnish considerable power, part of which has been utilized since early settlement. A mill run by water power was built in 1738 near the mouth of Saucon Creek, and scores of grist, saw, paint, powder, and paper mills have utilized power developed on the smaller streams. Some of the streams, like the Monocacy, are dry in parts of their courses for weeks. This lack of water has been the chief cause of the abandonment of many small mills, and at present less use than formerly is made of the streams.

The first waterway improvements on Lehigh River were made for the purpose of facilitating transportation of anthracite from Mauch

Chunk to Philadelphia by Lehigh and Delaware rivers, and the dams thus constructed later became the means of developing water power. In 1818 and 1819 the Lehigh Navigation Co. constructed 37 small wing dams and 13 cross dams along Lehigh River between Mauch Chunk and Easton. In 1820 the Lehigh Navigation Co. and the Lehigh Coal Co. united as the Lehigh Navigation & Coal Co., and in the following year the name was changed to the Lehigh Coal & Navigation Co. This company is now one of the most important coal and transportation companies of eastern Pennsylvania. A canal along Lehigh River was completed in 1829, and a canal along Delaware River below Easton was completed in 1831. Since then this canal system has been much used in the transportation of coal from the anthracite regions to Philadelphia and intermediate points. A flood in 1841 destroyed almost all the improvements on the Lehigh, but they were soon restored. The diversion dams in Lehigh River have become useful sources of water for power for several mills of different kinds along the canal.

Quality of surface waters.

With the exception of a few short branches all the streams flow through thickly inhabited farming or manufacturing districts and are consequently liable to pollution. The city of Bethlehem is the only municipality that obtains water for domestic use from any streams in the quadrangle, and this supply is purified by filtration. Farmers haul water from near-by streams for household use only during periods of drought. The Bethlehem Steel Co. and the Bethlehem Coke Co. pump water from Lehigh River and filter it to remove materials in suspension before it is used in boilers.

Lehigh River above the Allentown quadrangle receives much pollution as culm or fine waste from coal mines and as sulphur in the culm and waste coal, which is a source of acid. Part of the sulphur is oxidized to sulphuric acid and increases the proportion of sulphate in the river water at the expense of the carbonate. The injury by culm is not so great as formerly because little low-grade coal goes to the dumps and because the waste is now extensively utilized in filling old workings by flushing. But the sulphur still markedly affects the composition of the water of Lehigh River.

Samples of water were collected daily and analyzed as ten-day composites by the United States Geological Survey from Lehigh River at Bethlehem during 1906 and 1907, and the analyses are summarized in the accompanying table. The samples were collected from the intake of the Bethlehem City Water Co. opposite Calypso Island above the entrance of Monocacy Creek.

Average, maximum, and minimum conditions of the water of Lehigh River at Bethlehem from Sept. 11, 1906, to Sept. 26, 1907, inclusive.[1]

[R. B. Dole, M. G. Roberts, Chase Palmer, and W. D. Collins, analysts]

Constituents.	Parts per million.			Percentage of average anhydrous residue.
	Average	Maximum.	Minimum.	
Turbidity	14	55	1	
Suspended matter	21	107	4.8	
Coefficient of fineness	2.46	17.00	.56	
Total iron (Fe)	1.2	3.2	.4	
Silica (SiO_2)	8.8		4.0	9.4
Iron (Fe)	.10	.21	.09	.2[2]
Calcium (Ca)	14	20	7.6	15.0
Magnesium (Mg)	5.7	7.6	1.6	6.1
Sodium (Na)	6.4	15	5.8	6.8
Potassium (K)	1.4			1.5
Carbonate radicle (CO_3)	.0	4.8	.0	21.1
Bicarbonate radicle (HCO_3)	40	57	17	
Sulphate radicle (SO_4)	30	37	15	32.2
Nitrate radicle (NO_3)	2.2	1.8	1.9	2.4
Chlorine (Cl)	4.9	5.8	2.2	5.3
Dissolved solids	95	174	48	

[1]Detailed analyses published in U. S. Geol. Survey Water-Supply Paper 236, p. 70, 1909.
[2]Fe_2O_3.

The effect of acid mine waste on the water of Lehigh River is clearly shown by the predominance of sulphate over carbonate, for this undoubtedly would be a calcium carbonate water if the carbonate normally present had not been partly decomposed and replaced by sulphuric acid. Fortunately the normal alkalinity of the stream above Bethlehem is more than sufficient to react with the acid in the mine waste, and consequently the water at and below that point is alkaline, though its relative proportion of sulphate is abnormal. In a general way the content of dissolved matter during the sampling period was inversely proportional to the gage height; this unusual regularity is probably due to the influx of a relatively constant quantity of strong mine drainage into a fluctuating stream. No apparent relation existed between content of suspended matter and gage height. The analyses represent a calcium sulphate water that is low in mineral content and that has an average hardness of 58 parts per million. The content of scale-forming constituents ranges from 30 to 85 parts and averages 60 parts per million; the water would form in boilers a small amount of hard scale, but it would not foam in the boilers or corrode them, and the scale could be rendered softer by addition of a small amount of soda ash.

Daily tests of the hardness and alkalinity of the river water at Bethlehem from February, 1913, to January, 1914, by R. J. Wysor, formerly chief chemist of the Bethlehem Steel Co., indicate that total hardness as $CaCO_3$ ranged from 29 to 120 parts per million, and averaged 66 parts, and alkalinity as $CaCO_3$ ranged from 24 to 77 parts and averaged 40 parts. The hardness is roughly in inverse proportion to the river stage, but the relation is very irregular.

The accompanying table of mineral analyses shows that the water of Little Lehigh River and of Jordan, Monocacy, and Saucon creeks contains more dissolved mineral matter than that of Lehigh River or the canal. The creeks flow through limestone areas, whereas the Lehigh receives the greater part of its water from areas of less soluble rocks, so that this difference is readily explained. The sample of water from the canal was collected at Bethlehem, and the canal is fed from Lehigh River at the Allentown dam; consequently its water is softer than that of the Lehigh at Bethlehem, as the river receives above Bethlehem several hard waters.

Mineral analyses of the water of Lehigh River and its tributaries.

[Parts per million; all analyses except second by R. J. Wysor.]

	Canal at Bethlehem.	Lehigh River at Hokendauqua.[1]	Lehigh River a Bethlehem.	Little Lehigh River.	Jordan Creek.	Monocacy.	Saucon Creek.
Dates of collection	Jan. 20, 1914	----------	Jan. 1913-Feb. 1914	Jan. 29, Feb. 4, 1914	Jan. 29, Feb. 4, 1914	Jan. 29, Feb. 4, 1914	Jan. 29, Feb. 4, 1914
Number of analyses	1	1	12	2	2	2	2
Silica (SiO_2)	3.8	7	5.5	7.1	6.5	8.0	8.5
Iron (Fe)	2.8	2[2]	2.2	1.0	1.1	1.2	2.0
Calcium (Ca)	8.1	13	15	28	20	30	22
Magnesium (Mg)	4.3	8	5.1	13	8.8	12	10
Sodium and potassium (Na+K)	----------	12	7.6	23	5.2	12	12
Bicarbonate radicle (HCO_3)	6.2	40	41	102	49	102	89
Sulphate radicle (SO_4)	37	50	26	16	19	20	3.0
Chlorine (Cl)	5.0	6	8.3	12	8.6	3.6	4.2
Dissolved solids	87	118	105	278	148	226	142
Organic and volatile matter[3]	----------	----------	15	100	20	60	13
Total hardness as $CaCO_3$	38	----------	65	158	93	168	125

[1]Analysis by Thomas Iron Co.
[2]$Fe_2O_3+Al_2O_3$. Water slightly acid.
[3]Values approximate.

GROUND WATER.

Source.

Ground water has been utilized in all parts of the quadrangle, and yet complete data in regard to its development are not obtainable, on account of the long period of time since the region was first settled. Many of the wells were dug more than 100 years ago, and the present owners or occupants of the land can not furnish any information in regard to their depth or material penetrated. The accompanying table gives a list of the principal wells of the quadrangle and shows the geologic age of the strata from which they derive their supplies, together with other data.

Of the water that falls on the region in the form of rain or snow part is evaporated, part runs off into the streams at once, and part sinks into the soil. The relative proportions of these three quanti-

ties depends upon so many factors, such as the way in which the precipitation occurs, whether in heavy downpours or gentle rain, the temperature at the time of precipitation, the character of the ground, whether bare or covered with vegetation, whether soft or frozen, whether dry or saturated with water, and the slope of the surface that it is impossible to determine how much of the rainfall disappears into the earth to form the underground water.

Throughout the great limestone belt of the Allentown quadrangle where the slopes are gentle, the soil loose through cultivation, and the underlying rocks porous or cavernous, doubtless half or more than half of the annual precipitation finds its way into the underlying rocks. In many places in this belt sink holes are well developed and there is no surface run-off. In the regions of shales and gneisses, on the other hand, where the rocks are less soluble, the slopes steeper, and the country less cultivated, the direct run-off probably exceeds the quantity of water passing into the earth.

Part of the water that passes into the ground is drawn to the surface later through capillarity and is evaporated, part is discharged by vegetation, part emerges along the slopes of the hills as seeps or springs, part probably continues its passage to the ocean by underground channels, and part remains practically stagnant in the rocks. Though some of the deep-seated waters may originate a short distance beyond the confines of the quadrangle it is doubtful whether any large quantity of even the deepest waters has come from distant points. The rainfall of the region thus determines the quantity of underground water available. As the rainfall of the whole quadrangle can be computed from the table given below, and the probable amount consumed annually can be estimated, it is clear that the ground water at present has not been fully utilized.

WELLS OF ALLENTOWN QUADRANGLE.

WELLS IN CAMBRIAN AND

Location	Owner of Well	Year completed	Depth of well	Diameter of wel
			Ft.	In.
1-1¼ miles north of Siegfried	Borough of Siegfried	1913	1–300 1–200 1–200	8
Northampton	D. G. Dery Silk Mfg. Co.	1912	1–500 1–119	6
Northampton	Northampton Brewing Co.	1902	240	4
¼ mile northeast of Catasauqua	George Holton	1909	225	6
¾ mile east of Catasauqua	Borough of Catasauqua	------	220 240	8
Catasauqua	Crystal Ice Co.	1914	107	8
Catasauqua	A. F. Kostenbader Co.	1903	205	8
Catasauqua	Chas. L. Lehnert Brewery	1904	204	6
South Catasauqua	------	------	237	------
Mickley's Pike 1 mile west of Fullerton	Oscar Henninger	1911	125	6
North Allentown	Jordan Silk Dyeing Co.	1914	100	8
1 mile north of Allentown	Lehigh Silk Dyeing Co.	1913	229	8
Allentown	Allentown Iron Mfg. Co.	1909	157	8
Allentown-Adam's Isle	Allentown Boat & Swimming Club	1909	100	6
Allentown	Arbogast-Bastian Co.	1912	708	8
East Allentown	National Silk Dyeing Co.	1910	125	6
Allentown, Union Street	L. F. Grames & Sons	1911	404	8
Allentown, Jefferson and Lawrence Streets.	City of Allentown	------	------	------
Allentown	Horlacher Brewing Co.	1890 1897	270 230	8 6
Aineyville	Stuyvesant Silk Mill	1910	200	6
Aineyville	Keystone Textile Co.	1910	255	6
Emaus	Borough of Emaus	1910	260 325	8 10
Emaus	H. Kostenbader Brewing Co.	1910	270	------
Emaus	Emaus Silk Co.	1915	125	6
South Bethlehem, Fourth and Birch Streets.	Lehigh Valley Cold Storage Co.	1894 1914	200 250	4 10
South Bethlehem, Elm Street	South Bethlehem Brewing Co.	------	163	8
Bethlehem	Borough of Bethlehem	------	300	------
Bethlehem	Bethlehem Silk Co.	1900	400	10
Bethlehem	Groman Bros.	1911	100	6
1 mile north of Bethlehem	Borough of Bethlehem	------ ------ 1915	700 750 1,013	8 6 12-8
1 mile south of Shoenersville	Harvey Fenstermacher	1911	170	6
1⅜ miles northeast of Shoenersville	George Diefendorfer	1914	119	6
1⅓ mile south of Bath	George Danner	1914	161	6
1½ miles southwest of Bath	Bath Portland Cement Co.	------	196 200 250	6
½ mile north of Farmersville	Robert Person	1912	191	6
Farmersville	Wilson Arbogast	1912	265	6
⅜ mile north of Butztown	Arson Mosser	1913	110	6
Freemansburg	Wm. Weaver	1911	125	6
½ mile southeast of Redington	Emma Lerch	1913	262 180	6 6
North Hellertown	John Weaver	1910	150	8
Mountainville	Salisbury School	1914	153	6
Hellertown	H. F. Myers-Park Hotel	1907	106	6

[1]—Overflowed. [2]—4,000,000 gallons in 24 hours. [3]—Overflows. [4]—Overflowed 10 gallons

ORDOVICIAN LIMESTONES

Depth to principal water supply	Depth below surface to which water rises	Supply per minute	How obtained at surface	Quality	General Remarks.
Ft.	Ft.	Gal.			
70	20	100+	Air pump	Hard	Pump of 100 gallons capacity failed to lower water. Two wells gave combined flow of 450 gallons per minute for a period.
115	-------	50	Air pump	Hard	No water in 500-foot well; 119-foot well at south end of mill.
50 and 60	25—30	100	Air pump	Hard	Used for brewing.
190	55	10	Air pump	Hard	
220 / 240	18	1,000	Air pump	Hard	Supplies Catasauqua.
75	18	150	Reciprocating pump	Hard	Distilled and used in manufacturing ice.
30—75	-------	150	Air pump	Hard	Used in brewing.
200	80	80	Air pump	Hard	Used in brewing.
-------	-------	-------	-------	-------	Dry hole.
110	30	12	Air pump	Hard	
50 and 90	25	100	Air pump	Hard	
150 and 220	10	100	Air pump	Hard	Not thoroughly tested. Will pump more.
90 and 140	15	100	Suction pump	Hard	
Every 10 feet	15	40	Air pump	Hard	Alluvium 40 feet, then limestone.
300 and 425	[1]	350	-------	Hard	Struck quartzite at 600 feet then gneiss.
70	25	40	-------	-------	
380	20	70	-------	Hard	
-------	-------	[2]	-------	Hard	A spring, part of city water supply.
-------	6	-------	Steam pump	Hard	Used in brewing.
180	60	40	Air pump	Hard	Clay 160 feet, then limestone.
190 and 245	45	40	Air pump	Hard	
Every 20 Feet	-------	125 / 200	-------	Hard	Borough water supply.
-------	-------	-------	-------	-------	Sink hole. 230 feet of clay, then limestone: very little water.
110	70	50	-------	Hard	
48 and 130	14	200	Air pump	Hard	River fill and loose material, 175 feet.
175, 200, & 220	-------	800			
-------	54	100	Air pump	Hard	Used for brewing.
-------	-------	312	-------	Hard	No longer used.
-------	10	900	Suction pump	Hard	
-------	50	35	Air pump	Hard	Clay 70 feet, then limestone 30 feet.
[3]	-------	800	Air pump	Hard	The 1,013-foot well has 12-inch casing to 650 feet and then 8 inch casing. Borough water supply.
-------	[3]	800			
-------	[3]	1,480			
160	40	15	Air pump	Hard	
100	35	40	Air pump	Hard	Clay first 70 feet.
150	70	40	Air pump	Hard	Clay first 70 feet.
196	-------	100 / 200	Air pump	Hard	Supply for cement plant
185	70	20+	Air pump	Hard	Not thoroughly tested.
140 and 220	45	20+	Air pump	Hard	Not thoroughly tested.
70 and 100	35	15	Air pump	Hard	Clay first 35 feet.
115	60	15	Air pump	Hard	Clay first 92 feet.
Dry	-------	-------	-------	-------	First well dry.
-------	-------	20	Air pump	Hard	
80 and 135	45	100	Air pump		All in glacial or residual material.
130	30	15	Air pump	Hard	
106	[3]	300	-------	Hard	

a minute.

WELLS OF ALLEN

WELLS IN CAMBRIAN

Location	Owner of Well	Year completed	Depth of well	Diameter of well
			Ft.	In.
South Allentown	Borough of South Allentown	1914	225 176	------ ------
1 mile south of Rittersville	Allentown State Hospital	1913	160	8
¼ mile west of Rittersville	Lehigh Valley Traction Co.	1909	230	6
Seidersville	Robert Felker	1910	208	6
¾ mile south of Mountainville	Waldheim Camp Association	1912	325	8

WELLS IN PRE-

Location	Owner of Well	Year completed	Depth of well	Diameter of well
1 mile south of Rittersville	Allentown State Hospital	------	770 700 270	8
¾ mile south of Rittersville	Allentown Foundry-Hardware Co.	1913	220 120	6
South Allentown or Aineyville	E. F. Miller	1909	268 187	8 8
Summit Lawn 1¼ miles south of Mountainville.	Laura Kuntz	1912	186	6
Summit Lawn 1¼ miles south of Mountainville.	R. P. Stevens	1911	93	6
¼ mile south of Emaus	Mountain Water Co.	1910	200 120	8 8
¼ mile east of Emaus	Borough of Emaus	1909	700	6

WELLS IN TRIASSIC

Location	Owner of Well	Year completed	Depth of well	Diameter of well
Coopersburg	Gabriel Hosiery Co.	1909	160	8
Coopersburg	Borough of Coopersburg	1910	300	8

WELLS IN ORDOVICIAN

Location	Owner of Well	Year completed	Depth of well	Diameter of well
1½ miles northwest of Bath	Borough of Bath	1914	225	4

[1]—Overflowed. [2]—4,000,000 gallons in 24 hours. [3]—Overflows. [4]—Overflowed 10 gallons

TOWN QUADRANGLE—Continued.

SANDSTONES AND QUARTZITES.

Depth to principal water supply	Depth below surface to which water rises.	Supply per minute	How obtained at surface	Quality	Remarks.
160	----	225 }	Air pump	Medium	Supplies borough.
170	----	150 }		Soft	
----	----	80—160	Air pump	Soft	Used at dairy house.
180—215	32	50	Air pump	Soft	
190	90	15	Air pump	Soft	In quartzite, glacial till, 170 feet.
300	60	50	----	Soft	Loose surface material 90 feet.

CAMBRIAN GNEISSES.

----	90	35 to 80	Air pump	Hard	770-foot and 270-foot wells connected.
----	----	4 }	Air pump	Soft	Practically dry holes.
----	----	7 }			
80[4]	----	30 }	Air pump	Soft	Drilled to supply borough.
80[4]	----	70 }			
175	25	50	Air pump	Soft	
90	45	50	Air pump	Soft	
----	----	35 }	----	Soft	Sandstone on surface, but water-bearing beds consist of gneiss.
----	----	25 }	----		
120	----	Very small	----	Soft	Well abandoned.

SHALES AND SANDSTONES.

75 and 135	3	160	----	----	Red shale to 100 feet then red sandstone.
140 and 210	35	100	Air pump	----	Supplies borough in summer.

SHALES AND SLATES.

----	1½	----	Overflowed through pipe sunk 20 feet underground	Soft	Part of borough supply.

a minute.

As the amount of precipitation determines the quantity of underground water, the following rainfall statistics for Bethlehem, which is near the center of the quadrangle, are included.

Average rainfall at Bethlehem, Pa.

	Inches		Inches
January	3.64	July	4.64
February	3.73	August	4.35
March	3.80	September	3.39
April	2.86	October	3.20
May	3.93	November	3.40
June	4.41	December	3.48
			44.83

Occurrence.

As the conditions under which ground water occurs in the rocks depend largely upon the character of the rocks at or near the surface it is advisable to discuss separately the ground-water resources of the areas of Ordovician shales and slates, Cambrian and Ordovician limestones, Cambrian sandstones and quartzites, pre-Cambrian gneisses, and Triassic shales, sandstones, and conglomerates. They are discussed in the order named, which is the general order in which the rocks appear at the surface from north to south across the quadrangle. Each division occurs in a more or less regular band that crosses the quadrangle from northeast to southwest. (See areal geology map, Pl. II).

Water in the Ordovician shales and slates.

North of a line between Siegfried and Nazareth the rocks consist almost entirely of shales and slates, with a few lenses of interbedded limestones in the vicinity of Seemsville and some sandstone strata near Kreidersville. Though the usual dip of the strata is northwest the rocks have been so closely folded in many places that they dip in all directions. Where the beds have been jointed and faulted great veins of quartz and calcite have been formed.

As these rocks are relatively impervious little water percolates through them except in the joints and between the beds of the shale or along the cleavage planes of the slate. These openings are very narrow, and as the shales are almost insoluble there has been little enlargement of them by the moving water. The result is a very slow downward movement of the water and the almost complete absence of large underground streams such as characterize the limestone areas.

Near the surface the shales and slates become greatly disintegrated through the action of frost, so that much of the rain water percolates a short distance into the rocks. Consequently wells sunk into these rocks are practically assured of water at moderate depth, although not in large quantities. As the wells usually receive seepage at several depths the yield is more or less commensurate with the depth and diameter of the well.

Within the slate belt of the Allentown quadrangle there are no industries that require large amounts of water, and consequently no deep wells have been sunk. For farm use wells sunk to a depth of 20 feet in some places supply sufficient water, but in other places they must be sunk 60 or 100 feet. In the vicinity of Dannersville the wells range in depth from 20 to 60 feet. In general it is necessary to go deeper on the uplands close to the deep, narrow valleys than farther back on the divides.

About 4 miles north of Nazareth a 600-foot well that was drilled in the slate obtained a strong flow of water that rose to the surface. The drill probably broke into an open fissure caused by some displacement of the rocks, through which the water flowed in large volume. Other wells sunk to equal depths in the same vicinity might obtain only small amounts of water that would not rise to the surface.

Along the slopes of the narrow valleys there is much seepage and in many places the water emerges as springs. Many of the inhabitants of the region obtain their entire water supply from springs. The Northampton County Almshouse, 1½ miles west of Nazareth, is supplied with water from several springs that issue from the slate half a mile north of the buildings. The water is collected in a reservoir and piped to the buildings. The water-works were built in 1875. A well-known spring a short distance northwest of Nazareth Hall, Nazareth, and a few others near by supplied the town of Nazareth with water for nearly a century. These strong springs evidently reach the surface along well-defined fissures that were produced by earth movements and that extend to great depths. The water rises along them under artesian pressure.

The water from the Ordovician shales and slates is of excellent quality. The insoluble character of the rocks permits little mineralization, and the slow filtration through the slates removes surface contamination.

Water in the Cambrian and Ordovician limestones.

Ground water in limestone regions flows mainly in well-defined open channels formed by solution along ordinary joints or bedding planes, and the surface water passes into these underground channels. With the exception of Monocacy Creek, which heads in the

slate region, surface streams are practically absent in the limestone belt east of Catasauqua and Weaversville. Count Zinzendorf in a letter dated March 15, 1743, described the region between Bethlehem and Nazareth as "absolutely a desert without wood or water, and of such a nature that it never can be sold." Another writer[81] in 1799 said that "part of the road [between Bethlehem and Nazareth] runs through a tract of land, which is exclusively called the Dry Land, on account of its want of any creeks, rivulets, or springs above ground. It is however well settled; the inhabitants bring water for common use from the nearest spring or brook. This is often at the distance of one, and even two and three miles. Of late, however, prudent and able settlers have begun to dig wells, whereby the value of their lands is considerably enhanced."

As the water in the limestones is concentrated in definite channels one of these channels must be struck to obtain water, and the uncertainty of finding one of them has favored "water witching," which is still practiced in many regions, although repeatedly shown to have no scientific basis and to be entirely unreliable.

Some water is usually obtained at the contact between the loose residual and glacial loamy clay and the underlying compact limestones. Many wells 15 to 30 feet deep draw their supply from this horizon and obtain sufficient water for domestic use except in times of drought. The water in such wells is, however, easily polluted by surface drainage, and these wells are gradually being abandoned. In place of the abandoned shallow wells deep wells are sunk, or if these are not successful cisterns are used. In the region between Butztown and Tatamy probably more than half of the farmers depend on cistern water for household use, and cisterns are also extensively used in other sections of the limestone areas except along permanent streams.

Many deep wells have been bored in the limestones during the last few years, and most of them have been successful. One experienced driller states that he obtained fair supplies of water at depths of about 200 feet in about 70 per cent of the wells he drilled in the limestones of this section. As shown in the table (pp. 174-177) some wells procure very large supplies, a few of them from several different horizons, yet a hole may be sunk within a few feet of a strong well and still be dry on account of the impervious character of the solid limestone. For this reason dry wells before being abandoned should be dynamited in order to shatter the surrounding rocks. As the rocks have been greatly broken by folding and faulting water may be obtained more readily from these limestones than from those in other regions that have been less subjected to stresses.

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[81] Ogden, J. C., Excursion into Bethlehem and Nazareth in 1799, pp. 41-42, Philadelphia, 1805.

The water in most of the deep wells rises above the level at which it is struck, and it overflows from numerous wells, as shown in the table (pp. 176-179). In general the deep wells obtain water under the greatest pressure, but as no regularity exists locations where flowing wells can be obtained can not be predicted.

Many springs are found in the limestone areas. Some of them are unusually strong, being underground streams that rise to the surface under artesian pressure. Some of them have been important sources of municipal water supply. The spring at Bethlehem that supplied the borough with water for nearly 170 years furnished more than 800 gallons a minute. Crystal Spring, the source of water supply for Allentown for many years, which yielded more than 4,000 gallons a minute, and the springs along Lehigh River that supplied Hokendauqua are the best known. Christian Spring, 2 miles west of Nazareth, and Menges Spring, three-quarters of a mile northwest of Mountainville, are also well known. A large spring that emerges near Monocacy Creek 1¼ miles south of Hanoverville may be part of the creek which follows an underground course for a few miles instead of following the great bend of the creek past Brodhead. Crystal Cave, half a mile northeast of Hellertown, contains a stream of water that probably comes to the surface as seepage in low marshy land a short distance away. Numerous smaller springs in many places are drawn upon by the inhabitants of the region, and also furnish much water to the surface streams, many of which, such as the small stream that passes through Butztown and Middletown, are almost entirely dependent upon springs.

All the springs of the region are affected by drought, and many disappear in summer, though the larger ones just mentioned have never been known to fail entirely.

All the ground water of the limestone areas is hard because of the mineral matter it dissolves in passing through the soluble rocks. The amount of material in solution ranges within wide limits owing to the differences in distance through which the water has flowed, the length of time it has remained in contact with the rocks, and the relative solubility of the inclosing limestones. This water causes the formation of much scale in boilers. In drinking water the mineral matter, mainly calcium, magnesium, and bicarbonates, is not regarded as detrimental. Analysis 1 in the table of analyses (p. 189) shows the composition of a limestone water.

The limestone waters are subject to contamination, as the areas are thickly settled and surface waters in many places find ready access to underground channels. Limestone waters near cities and towns, whether from wells or from springs, should be treated with hypochlorite of lime on account of the sewage that is continually poured into the underground channels and should be examined bac-

teriologically from time to time to ascertain the extent of contamination. If wells are tightly cased for some distance into the solid rock the danger of surface contamination is lessened, but it is not entirely removed, as polluted waters may reach great depths through open fissures with practically no filtration. Doubtless a complete sanitary survey of the region would demonstrate that many of the sources are too badly polluted for safe use.

Water in the Cambrian sandstones and quartzites.

The band of sandstones and quartzites along the sides of the South Mountain has been prospected for water in few places, mainly on account of the narrowness of its outcrop. The quantity of water encountered in the operation of the limonite iron mines in this belt of rocks between Emaus and Mountainville and in the narrow valley 1½ miles southeast of Hellertown proves that these sandstones and quartzites contain much water. The water passes along joints and bedding planes or through the rocks themselves and is seldom concentrated in definite streams, except in places where the rocks have been broken and displaced by earth movements. The best place to procure water is at the contact between these rocks and the underlying gneisses. The borough of Emaus drove a tunnel into the mountain, starting in the quartzite and passing into the gneiss. At the contact considerable water enters the tunnel, but the quantity is inadequate. The same contact 100 feet lower would probably have furnished a much larger supply.

The best place to sink wells in these rocks is a short distance beyond the point where they disappear beneath the limestones. As the rocks near the mountain almost invariably dip steeply, the sandstones or quartzites are within a short distance carried beyond the depth at which they are available as sources of water. Springs are not numerous in these rocks, but there are some in places where the rocks have been shattered.

The water from the Cambrian quartzites and sandstones is low in mineral content because of the insoluble character of the rocks with which it comes into contact, and it is uncontaminated because the slopes of the mountain are sparsely settled.

Water in the pre-Cambrian gneisses.

The pre-Cambrian gneisses form the mountains in the southern half of the quadrangle. These regions are thinly settled on account of the steep slopes and the stony character of the soils, which are only locally suitable for cultivation. The rocks near the surface are greatly jointed and permit the entrance of water. As the depth increases the joint spaces become narrower and consequently the

water moves more slowly. Lines of seeps or springs furnish most of the residents of the region with ample supplies of water. Wells 10 to 25 feet deep yield fair supplies.

Half of the deep wells that have been bored have been failures. If water is not obtained within 200 feet it is generally regarded as useless to continue to lower levels. A few excellent wells have been obtained in the gneisses of the quadrangle, but most of them yielded only small quantities. The borough of Emaus bored a well to the depth of 700 feet in the gneiss but obtained no water except near the surface.

The water in the gneiss contains little dissolved mineral matter, and when it is protected from local pollution it is very desirable. In a few places where pyrite is an abundant constituent of the gneisses the water may contain iron.

Camel's Hump Spring, on the north slope of Quaker Hill, rises along a fault plane, but the water is derived entirely from the gneiss. The water from this spring has long been marketed in the near-by towns. An analysis of it is given in the table of water analyses (p. 189.)

In 1845 Dr. F. A. Oppelt established a "hydropathic asylum" in Bethlehem, where St. Luke's Hospital is now located, which used the water from a fine spring that emerges along a fault plane between the gneiss and the limestone. The establishment, which was known as "Oppelt's Water-Cure," was operated until 1875, when the property was sold to the trustees of St. Luke's Hospital. It is said that over 3,000 people were treated in the institution.

A hotel and resort was also run at Leuchanweki Springs, Bethlehem, for many years. The water, which seems to come from the gneiss, is pure and wholesome.

Water in the Triassic shales, sandstones, and conglomerates.

The beds of Triassic rocks in the southeastern part of the Allentown quadrangle are gently inclined and do not have sharp folds and faults, such as are characteristic of the limestones and Ordovician shales and slates. Water percolates slowly through the shales, following the narrow openings along joints and between the beds. When it reaches sandy beds the water tends to flow in them on account of their porous character. Small amounts of water can be obtained in most places in the shales, but where a sandy or conglomeratic layer is penetrated a good supply is assured. The Coopersburg wells are the only deep ones in the region regarding which information could be obtained. Wells 15 to 35 feet deep supply most of the water required for domestic use.

The Triassic rocks are unlike the other rocks of the quadrangle in that they can be depended upon to furnish water at definite

horizons. The wells in any locality are approximately of equal depth, as they derive their water from the same bed or beds of nearly horizontal porous rock. There are no data to show how far these water-bearing beds extend, but the variable character of the Triassic rocks indicates that they underlie small areas, within which, however, they are well marked.

Springs are rare, except along the contacts with other rocks, especially the diabase, which is intruded within the sedimentary strata east of Coopersburg.

The water of the Triassic rocks is of good quality on account of the insoluble character of the rocks and the filtering which the water undergoes as it percolates through them.

Municipal Supplies.

Allentown.—The water supply of Allentown is obtained from two springs. The chief source is Schantz's Spring, about 5 miles from the city, in Lower Macungie Township, in the Slatington quadrangle. Hard limestone water is pumped from this spring into the Allentown reservoir at the rate of 8,000,000 gallons a day against a head of 167 feet. Crystal Spring, at Jefferson and Lawrence streets, Allentown, is the other source. It is pumped against a head of 255 feet at a rated capacity of 4,000,000 gallons a day. The water is higher in chlorine than some others in the vicinity. The water is not filtered but is treated with chloride of lime. The character of the water of this spring is shown in the table (p. 189).

A vast supply of water in the future is planned to be taken from Little Lehigh Creek. About 40,000,000 gallons a day can be procured from this source without difficulty. The water is softer than that of Crystal Spring. It is proposed to filter this water for domestic and industrial use.

Bath—The borough of Bath derives its water supply from two springs and a 225-foot well 1½ miles northwest of the borough limits. The well was bored in 1914 for an additional supply of water. It is 4 inches in diameter, and the water rises within 1½ feet of the surface. From a point 20 feet below the surface the water flows through a cross pipe to the reservoir, into which the water from the two springs also flows. The water from the springs and the well comes from the slates and is of excellent quality. Its character is shown in the table of analyses (p. 189).

Bethlehem (north side of Lehigh River).—The first successful waterworks in Pennsylvania was established in 1754 at Bethlehem, when the water of a large spring on the east side of Monocacy Creek, back of the site of the present Hotel Bethlehem, was forced by means of water power developed by Monocacy Creek through wooden pipes to a tower between Community House and the Sisters' House

and thence distributed throughout the borough. This spring continued to supply practically all the water required for the borough until 1912. A 300-foot well was then drilled between the spring and the creek, but the water was so badly contaminated by sewage that it could not be used. Water from a 390-foot well at the Bethlehem Silk Mill, half a mile farther north, was used to supplement the spring supply. The spring finally, however, became contaminated and had to be adandoned. At times it yielded 1,200,000 gallons a day, and the 300-foot well furnished 460,000 gallons a day.

In 1912 Bethlehem began to use the water from two wells at Illick's Mill, on Monocacy Creek about 1½ miles north of Bethlehem. These wells, which are 700 and 750 feet deep, overflow, but they must be pumped in order to obtain a sufficient supply. Together they yield 2,000,000 gallons a day. A third well, 1,013 feet deep, was completed on the same property just east of the creek in March, 1915. Tests show it to have a capacity of 1,351 gallons a minute, or approximately 2,000,000 gallons a day.

The water from the spring and the wells is hard. The wells throughout their depth were in limestone. As the limestones are cavernous and the region is thickly settled it is necessary to watch the water carefully and to make frequent bacteriologic examinations. It is, however, seldom necessary to add hypochlorite of lime, though equipment for that purpose has been installed.

Bethlehem (south side of Lehigh River).—The South Bethlehem Gas & Water Co. built works in 1865, taking water from Lehigh River. The Mountain Water Co. was chartered in 1893 to supply water in Bethlehem Township from springs on the mountain near Seidersville. The two companies united in 1894 under the name of the Bethlehem Consolidated Water Co., which sold its franchises and properties in 1903 to the Bethlehem City Water Co. The City of Bethlehem has recently purchased the company. It obtains its water from the two sources mentioned, and until recently it furnished water to Bethlehem (South side), Fountain Hill, Northampton Heights, Bethlehem (West side), Rittersville, East Allentown, and the State Hospital for the Insane at Rittersville. Its service is now limited to Bethlehem and Fountain Hill. Some houses still receive spring water from the side of the mountain, where Tinsley Jeter built a reservoir in 1866 near Bishopthorpe School. Pipes were laid from this reservoir through several streets as far as Union Station. In 1872 the Cold Spring Water Co. laid pipes from springs on the side of the mountain near Delaware Avenue to a few residences on Fountain Hill. The Bethlehem Steel Co. has also a private supply from a spring on the side of the mountain.

The river supply of the City of Bethlehem is pumped from a dug well near the river to reservoirs on the side of the mountain above St. Luke's Hospital. In sinking the well several flows of water were obtained from the quartzite beds that were penetrated. The well was sunk under the impression that water from Lehigh River would filter through the alluvial material and fill it. During that part of the year when the flow from the springs is greatest, however, about 75 per cent of the water pumped is probably furnished by the springs, but during droughts the river must supply nearly all the water needed. The spring water is of excellent quality, as it contains little mineral matter in solution and is free from contamination. The river water, on the contrary, must be filtered on account of the sewage poured into the river from the cities farther upstream. The acids from the waters of the coal mines along the upper course of the river are sufficient to destroy many of the bacteria, although not all.

From the well the water is pumped into a sedimentation reservoir 420 by 220 feet and 21 feet deep, which has a capacity of 14,000,000 gallons. It then passes through six preliminary filters and six open slow sand filters having a capacity of 4,000,000 gallons a day. The filtered-water reservoir holds 5,000,000 gallons. The filtered water can be treated with hypochlorite of lime when that is necessary. Analyses of the water of Lehigh River are given in the table on pages 170-171.

The spring supply, which comes from the springs of the Mountain Water Co., is piped to a masonry reservoir holding 300,000 gallons.

Catasauqua.—The main part of Catasauqua was formerly supplied with water by the Clear Springs Water Co., but it is now supplied from two wells that have been drilled by the borough in limestone east of the town to depths of 240 and 220 feet respectively. An excellent supply of hard water was encountered at these depths, the combined yield of the wells being 1,000 gallons a minute.

Clear Springs Water Co.—The Clear Springs Water Co. has contracted to supply water to the boroughs of Siegfried, Northampton, Cementon, Coplay, Hokendauqua, North and West Catasauqua, and Fullerton. The company procures its water in Lehigh County from Liesenring Spring near Cementon, and Yellis Creek. Both sources are beyond the borders of the Allentown quadrangle. The spring is used to supply the town of Cementon only, and the water is distributed by gravity. Yellis Creek is supplied largely by springs. It furnishes excellent soft water which is pumped into a reservoir at Spring Mill, 325 feet above the surrounding country. The supply is purified by filtration through rapid sand filters. The average daily consumption is 1,000,000 gallons. In summer, when the supply from Yellis Creek is insufficient, water is pumped from Lehigh River into the reservoir.

Coopersburg.—The borough of Coopersburg obtains its regular supply of water for domestic use from springs east of the village. As this source is insufficient during summer, a 300-foot well with a capacity of 100 gallons a minute was drilled in 1910. This well was drilled through red shale and red sandstone of Triassic age. The principal water-bearing beds were struck at 140 and 210 feet, and the water rises within 35 feet of the surface. The well is 8 inches in diameter, and an air pump is used to force the water to the surface. This well, together with the spring supply, is sufficient for all purposes.

Coplay.—Coplay is supplied with water for domestic and industrial use by the Clear Springs Water Co. of Catasauqua.

East Allentown.—The borough of East Allentown was supplied with water by the Bethlehem City Water Co. until recently. It is now supplied by the City of Allentown.

Emaus.—For many years the borough of Emaus obtained its water supply from a well near the Perkiomen Railroad, within the limestone area. After the water in this well became contaminated a spring on the side of the mountain was utilized. A tunnel that was run into the mountain passed through two shattered places in the gneiss, from which small amounts of water were obtained. Later a 700-foot well was drilled near by. Loose material was penetrated to a depth of 120 feet, where a small amount of water was procured. The deeper drilling was in Cambrian sandstones and the underlying gneiss. As samples were not carefully preserved the depth at which the drill apparently passed from the sandstone into the gneiss can not be stated, but apparently no water was found at the contact or in the gneiss below, and the well was abandoned. The borough now receives most of its water from a 325-foot well near the place where the water was originally obtained. The water apparently is uncontaminated, though it is high in mineral matter, as it comes from the limestone. The spring and the tunnel furnish part of the water, and this water from the sandstone and gneiss is of excellent quality.

Fullerton.—The borough of Fullerton procures the greater part of its water from the Clear Springs Water Co.

Hellertown.—Two springs furnish most of the water consumed by the residents of Hellertown, though several large artesian wells add to the supply. The springs, which are owned by the borough of Hellertown, are in the mountains southeast of the village. The water which emerges from the pre-Cambrian gneiss is soft and excellent in quality. It flows into a 1,000,000-gallon reservoir that is inclosed by a high picket fence and is protected against pollution by surface drainage.

During summer the reservoir frequently overflows; shortage occurs from October to January, however, and an option has been taken on two springs on the Koch property, 1 mile east of the reservoir. A pressure of 120 pounds to the square inch is maintained by the present system. Recent tests of Eichelberger Spring as a source of additional water supply showed a flow of only 34,000 to 37,000 gallons a day.

Hokendauqua.—Hokendauqua receives its water from the reservoir of the Clear Springs Water Co.

Nazareth.—The water supply of Nazareth is purchased from the Blue Mountain Consolidated Water Co., which obtains soft water of excellent quality from a small stream and two wells on the north side of Blue Mountain near Wind Gap.

Northampton.—The borough of Northampton is supplied by the Clear Springs Water Co.

Northampton Heights.—The former borough of Northampton Heights now a part of Bethlehem is supplied with water by the City of Bethlehem.

Rittersville.—Rittersville now a part of Allentown is supplied with water by the City of Allentown.

Siegfried.—Three wells were drilled north of Siegfried in 1913 in order to supply the borough. One is 300 feet deep, and the others are 200 feet deep; the principal water-bearing stratum was at 70 feet in each well. The wells are 8 inches in diameter and yield 600 gallons a minute. Two of them yielded 450 gallons a minute during a prolonged test, and a 10-inch hole that was drilled near by later yielded much water. Despite these satisfactory results, the water supply is now purchased from the Clear Springs Water Co., and the wells are held for emergency.

South Allentown and Aineyville.—Two wells, which were drilled 267 and 187 feet in gneiss in the rear of Miller's hotel, South Allentown, yielded only 30 gallons and 70 gallons a minute respectively, but two wells drilled later by the borough through glacial drift and clay into limestone are more satisfactory. One is 225 feet and the other 176 feet deep. The principal water-bearing stratum was struck at 160 to 170 feet in both wells. The larger well yields 324,000 gallons and the smaller one 216,000 gallons a day. The level of the water is 137 feet below the surface. The water is raised from this depth into a 120,000-gallon standpipe. The chemical character of the water is shown by the analyses in the table (p. 189).

West Catasauqua.—West Catasauqua is supplied by the Clear Springs Water Co.

Other towns.—Private wells 18 to 100 feet deep supply water to the residents of Butztown, Center Valley, Freemansburg, Lanark, and Pleasant Valley, though cistern water is extensively used in these localities. Wells at Butztown, Center Valley, and Lanark yield hard water from the limestone. Numerous springs furnish water for people in Spring Valley (Saucona) and vicinity, but no permanent supply for domestic use is available in Tatamy, and residents there depend entirely on cistern water.

Analyses of ground waters in Allentown quadrangle.

[Parts per million.]

Constituents	1	2	3	4	5
SiO_2	1				
$Fe_2O_3+Al_2O_3$	3		.3[1]		
Ca	48				
Mg	29				
Na+K	14				
CO_3					
HCO_3	245		221		196
SO_4	35				
Cl	21	1.2	21	4.5	2.2
Organic and volatile matter	2	2.4	16	15	50
Total solids	274	40	271	71	1[illegible]5
Total hardness as $CaCO_3$		13	243		67

[1]Iron.

1. From 290-foot well of Bethlehem Silk Mills, Bethlehem, Feb., 1907. Water from limestone.
2. Camel's Hump Spring on north slope of Quaker Hill. Analysis by W. H. Chandler. Water from pre-Cambrian gneiss.
3. Crystal Spring, Allentown.
4. From 225-foot well near Bath, Jan. 16, 1915. Analysis by S. P. Sadtler.
5. Well-water supply of South Allentown.

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V

W

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U. S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

PENNSYLVANIA DEPARTMENT OF FORESTS AND WATERS
R. Y. STUART, SECRETARY
TOPOGRAPHIC AND GEOLOGIC SURVEY
GEORGE H. ASHLEY, STATE GEOLOGIST

TOPOGRAPHIC AND GEOLOGIC
ATLAS OF PENNSYLVANIA
SHEET 206, ALLENTOWN AREA, PLATE I

Base from U. S. Geological Survey topographic map of Allentown quadrangle, Pennsylvania
Surveyed in 1893

MAP OF THE ALLENTOWN QUADRANGLE, PENNSYLVANIA

Showing Topography

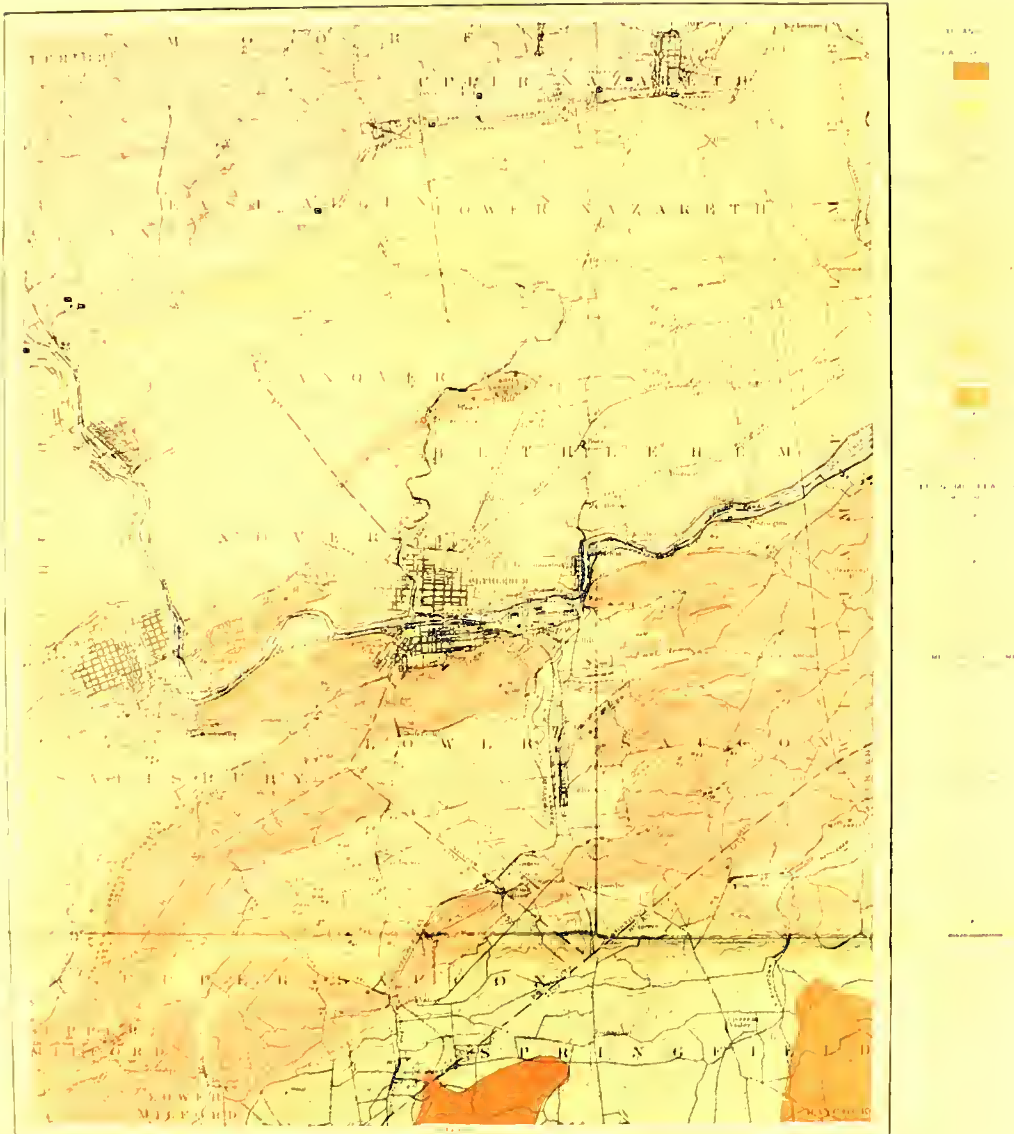
Scale 62500

Contour interval 20 feet

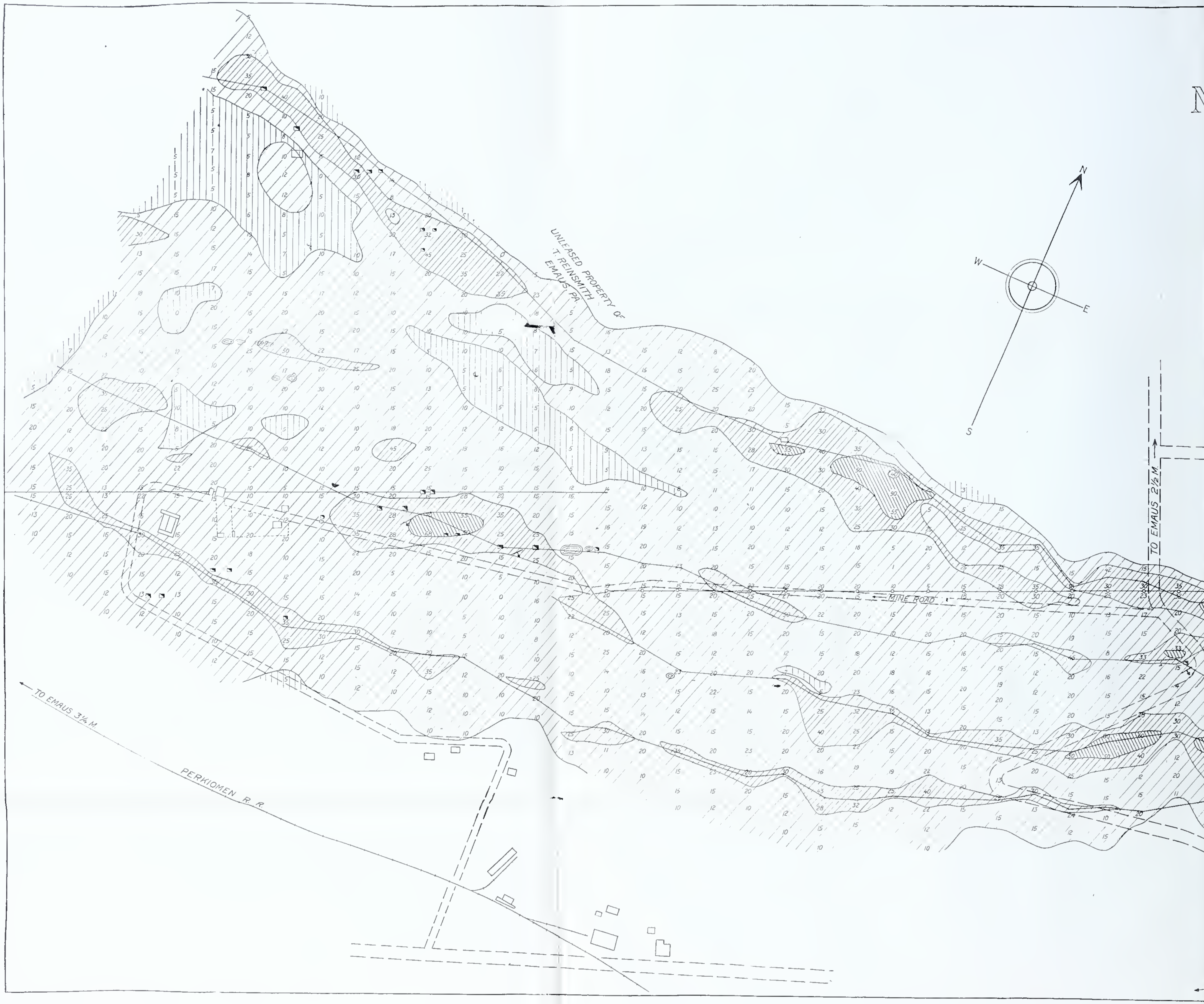
Datum is mean sea level.

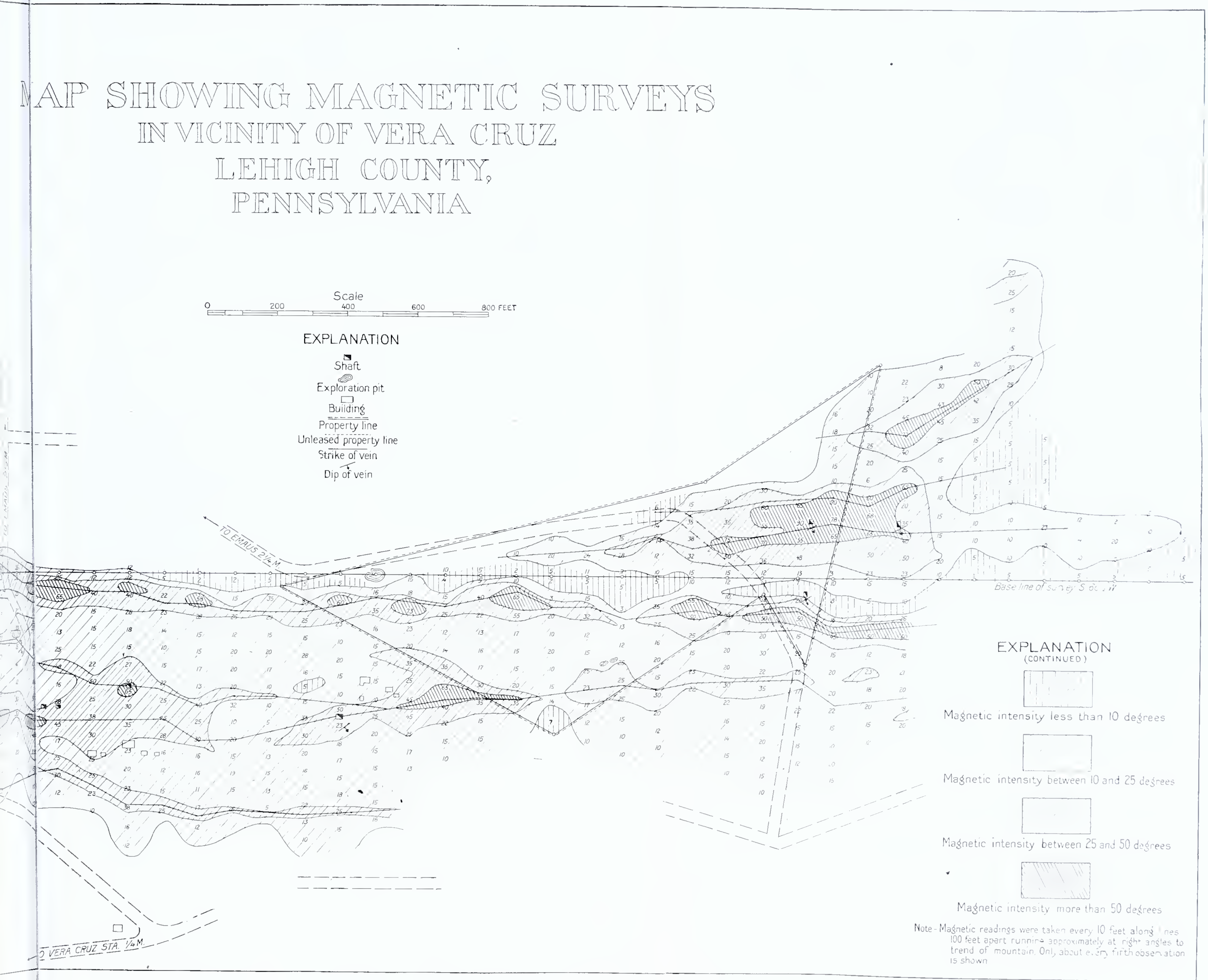
1925

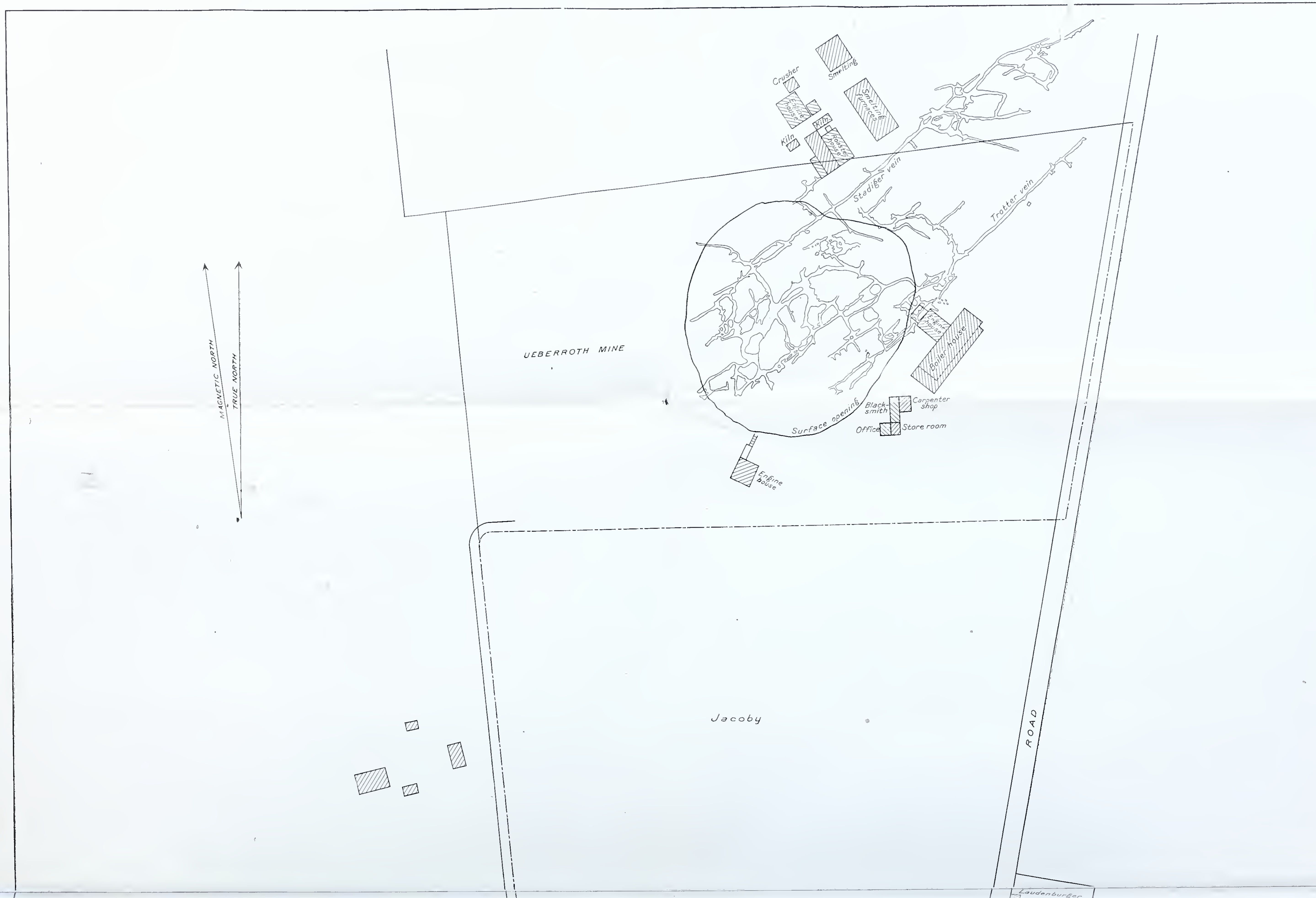
Additional railroads added 1910 by B. L. Miller and from data furnished by the several railroads. City streets extended from maps by city engineers, 1924



MAP OF THE ALLENTOWN QUADRANGLE, PENNSYLVANIA


UNLEASED PROPERTY OF
T. REINSMITH
EMAUS PA.
N
W
E
S
TO EMAUS 2½ M.
MINE ROAD
TO EMAUS 3¼ M.
PERKIOMEN R.R.


MAP SHOWING MAGNETIC SURVEYS
IN VICINITY OF VERA CRUZ
LEHIGH COUNTY,
PENNSYLVANIA
Scale
0 200 400 600 800 FEET
EXPLANATION
Shaft
Exploration pit
Building
Property line
Unleased property line
Strike of vein
Dip of vein
TO EMAUS 2 1/4 M.
Base line of survey
TO VERA CRUZ STA. 1/4 M.
EXPLANATION
(CONTINUED)
Magnetic intensity less than 10 degrees
Magnetic intensity between 10 and 25 degrees
Magnetic intensity between 25 and 50 degrees
Magnetic intensity more than 50 degrees
Note - Magnetic readings were taken every 10 feet along lines 100 feet apart running approximately at right angles to trend of mountain. Only about every fifth observation is shown


Crusher
Smelting
Engine house
Smelting furnaces
Kiln
Kiln
Roaster house
Stadiger vein
Trotter vein
Engine house
Boiler house
Carpenter shop
Black-smith
Store room
Office
Surface opening
Engine house
UEBERROTH MINE
MAGNETIC NORTH
TRUE NORTH
Jacoby
ROAD
Laudenburger

Map showing locations and developments of the Friedensville zinc mines.